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Users' Manual for Computer Code ICYL

Cylindrical Seals Lubricated by Incompressible Fluids

Antonio F. Artiles
Mechanical Technology, Inc., Latham, New York

October 2005

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NOMENCLATURE

A, B	misalignment of rotor about the x and y axes, respectively. [radians]
$b_{ij} = B_{ij}\,(C^3/12\mu R^4)$	dimensionless damping coefficient matrix, where $i,j = x, y, \alpha, \beta$.
C	nominal clearance. [L]
e_b, e_j	roughness of the housing and journal surfaces. [L]
e_x, e_y	components of rotor eccentricity at $Z=0$. [L]
e	rotor eccentricity at $Z=0$. [L]
F_x, F_y	components of fluid film force about x and y axes. [F]
$f = F/(P_oR^2)$	dimensionless fluid film force.
H	local film thickness. [L]
H_o	local film thickness for the concentric aligned rotor (i.e., $e_x = e_y = A = B = 0$). [L]
$h = H/C$	dimensionless local film thickness.
K_e	coefficient of pressure drop at inlet to film.
K_{ij}, B_{ij}	Stiffness and damping coefficient matrices, where $i,j = x, y, \alpha, \beta$.
$k_{ij} = K_{ij}\,(C/P_oR^2)$	dimensionless stiffness coefficient matrix, where $i,j = x, y, \alpha, \beta$.
L	seal length. [L]
M_x, M_y	components of fluid film force about x and y axes. [F-L]
$m = M/(P_oR^3)$	dimensionless fluid film moment.

$\hat{n}$	unit vector normal to fluid film boundary.
P	local pressure. [F/L^2]
$p = P/P_o$	dimensionless local pressure.
P_l, P_r	Left and right boundary pressures. [F/L^2]
P_p, P_s	Pocket and supply pressures. [F/L^2]
P_o	Reference pressure, used for scaling the pressure field, which is normally set equal to P_s, P_p, P_l or P_r. [F/L^2]
Q_r	flow from pocket or recess. [L^3/T]
$q_r = Q_r\,(12\mu/P_oC^3)$	dimensionless flow from pocket or recess.
R	seal radius. [L]
$Re^* = \rho h^3 \nabla p/\mu^2$	local Reynolds number based on pressure-driven flow.
$Re_o^* = \rho C^3 P_o/(R\mu^2)$	reference Reynolds number based on pressure-driven flow.
t	time. [T]
$u = U\,(12\mu R/C^2P_o)$	dimensionless circumferential component of fluid velocity.
$v = V\,(12\mu R/C^2P_o)$	dimensionless axial component of fluid velocity.
U, V	circumferential and axial fluid velocity components, averaged across the film. [L/T]
U_b, U_j	linear velocity of housing and journal surfaces (equal to $R\omega_b$, $R\omega_j$, respectively). [L/T]
X,Y,Z	cartesian coordinates. [L]
$z = Z/R$	dimensionless axial coordinate.

$\alpha = A\ (2L/C)$	misalignment ratio about the x-axis.
$\beta = B\ (2L/C)$	misalignment ratio about the y-axis.
$\epsilon_x,\ \epsilon_y$	components of rotor eccentricity ratio.
$\epsilon = e/C$	rotor eccentricity ratio.
θ	circumferential coordinate. [radians]
$\Lambda_b = 6\mu U_b R/(C^2 P_o)$	dimensionless velocity of housing surface.
$\Lambda_j = 6\mu U_j R/(C^2 P_o)$	dimensionless velocity of rotor surface.
$\Lambda_r = \rho C^6 P_o/(288\ A_o{}^2 C_d{}^2 \mu^2)$	coefficient of orifice restriction.
$\Lambda_e = K_e\ (Re_o{}^* C/288\ R)$	coefficient of pressure drop at inlet to film.
μ	fluid dynamic viscosity. [F-S/L^2]
ρ	fluid density. [F-T^{2}L^{-4}]
$\omega_b,\ \omega_j$	angular velocity of housing and journal surfaces. [rad/T]
$\tau = t\ (C^2 P_o/12\mu R^2)$	dimensionless time.

1.0 INTRODUCTION

Incompressible cylindrical seals are used to reduce leakage from higher pressures. The pressures generated in plain cylindrical seals with incompressible fluids typically result in forces which are normal to the displacement and therefore tend to destabilize the rotating shaft. Surface roughness, geometry alterations, and external pressurization are ways in which the direct stiffness and damping coefficients can be improved and the cross-coupled stiffness decreased in order to improve stability.

The computer code ICYL was developed to evaluate the performance of cylindrical seals operating with incompressible fluids. The pressure and velocity distributions within the seal clearance are first evaluated from the governing equations. From these, design quantities such as seal leakage flows, power loss and resulting forces and moments are calculated. Minimum film thicknesses and maximum pressures as well as critical rotor-dynamics coefficients such as stiffness, damping and critical mass are evaluated.

Program capabilities:

1. 2-D incompressible isoviscous flow in cylindrical geometry.
2. Rotation of both rotor and housing.
3. Roughness of both rotor and housing.
4. Arbitrary film thickness distribution, including features such as steps, pockets, tapers and preloaded arcs
5. Rotor position described by four degrees of freedom (translational and rotational)
6. Up to 32 dynamic coefficients as well as the critical mass may be calculated for use in rotor-dynamic design, including system response and stability calculations.

7. External forces and moments may be prescribed independently to find rotor position.
8. Pocket pressures or orifice size are prescribed.
9. Laminar or turbulent flow.
10. Cavitation.
11. Inertia pressure drop at inlets to fluid film (from ends of seal and from pressurized pockets).

Assumptions

1. The film thickness is assumed to be small compared with seal lengths and diameters but large compared with surface roughness.
2. Pockets supplied from an external pressure source through an orifice restriction are assumed to be sufficiently deep that the pressure is constant within them.
3. Wall roughness is assumed to be isotropic and represented by an "equivalent sand roughness" height.
4. Fluid inertia effects in the film are negligible.

2.0 THEORETICAL DESCRIPTION AND NUMERICAL METHODS

Figures 1, 2 and 3 illustrate the geometry of a cylindrical seal as well as the coordinate system used here to describe it. Figure 1 shows the seal housing of length L separated from the rotor by the film thickness H. The coordinate system is placed at the mid-length of the seal with the circumferential coordinate θ measured from the x-axis. Figure 2 illustrates the displaced, misaligned rotor, while Figure 3 shows an axial cross-section of the film thickness.

The film thickness and time rate-of-change thereof are written:

$$H = H_o - (e_x + ZB)\cos\theta - (e_y - ZA)\sin\theta$$
$$\frac{\partial H}{\partial t} = -\left(\frac{\partial e_x}{\partial t} + Z\frac{\partial B}{\partial t}\right)\cos\theta - \left(\frac{\partial e_y}{\partial t} - Z\frac{\partial A}{\partial t}\right)\sin\theta \qquad (1)$$

where H_o, an arbitrary function of film coordinates (θ, Z), represents the film thickness distribution for a rotor that is aligned and centered with the housing. e_x and e_y represent the components of rotor eccentricity at the seal mid-length, while A and B represent the angles of rotor rotation about the x and y axes, respectively. The former are referred to as the radial or lateral displacements and the latter as the angular displacements.

2.1 Governing equations

The equations governing the flow of incompressible fluids in thin films are obtained [10,11,15] by integrating the Navier-Stokes momentum and continuity

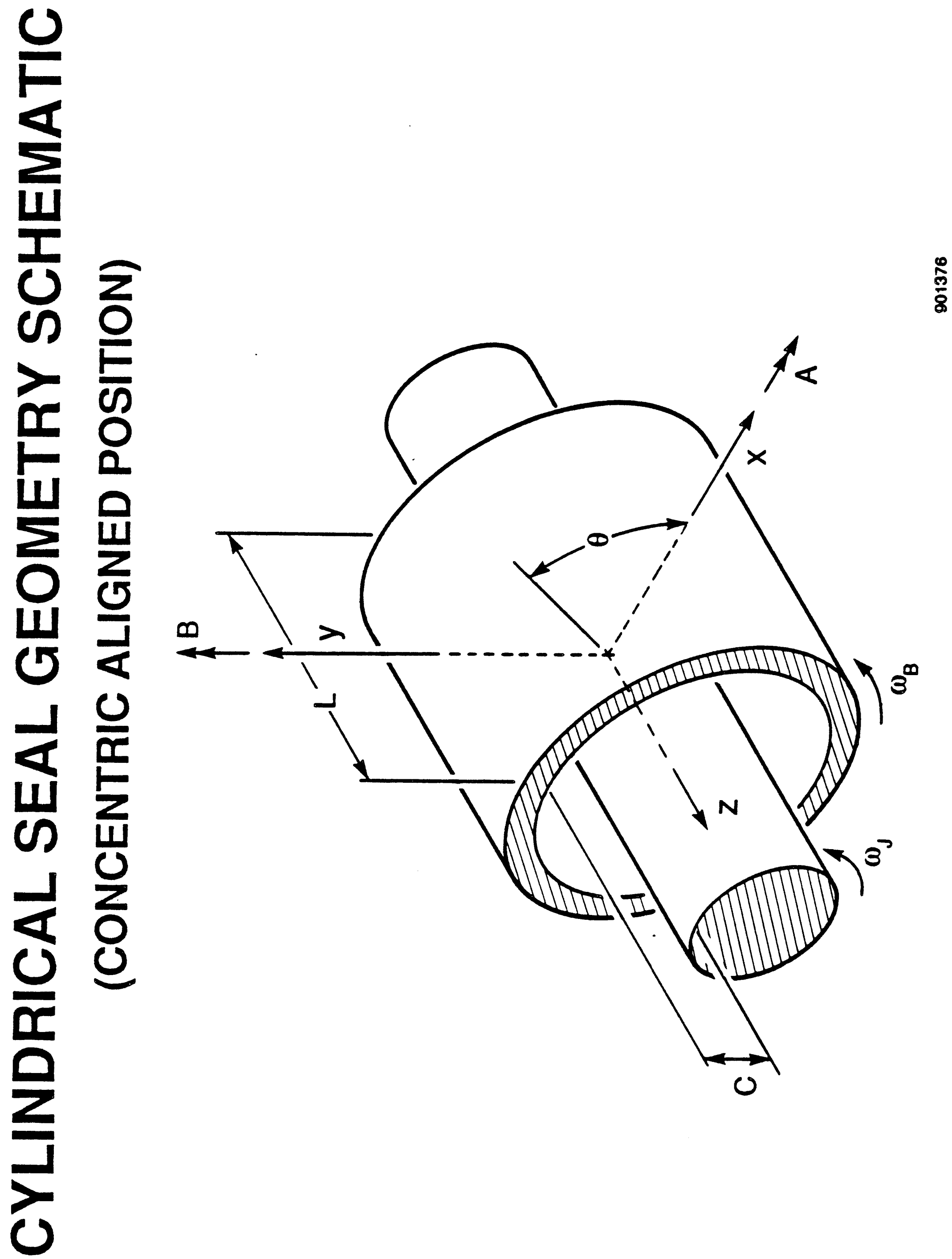

Figure 1 Cylindrical seal geometry

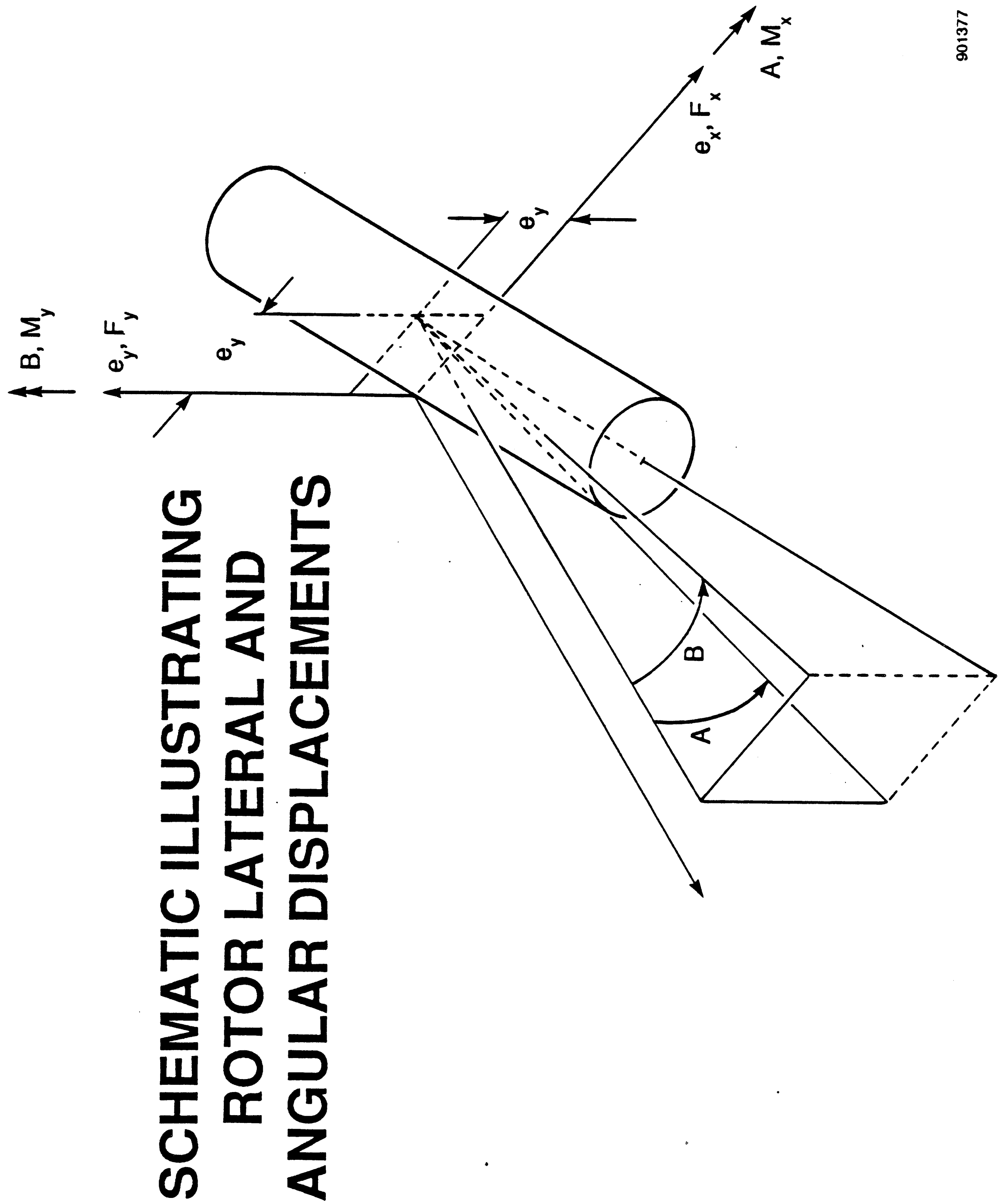

Figure 2 Rotor with lateral and angular displacements.

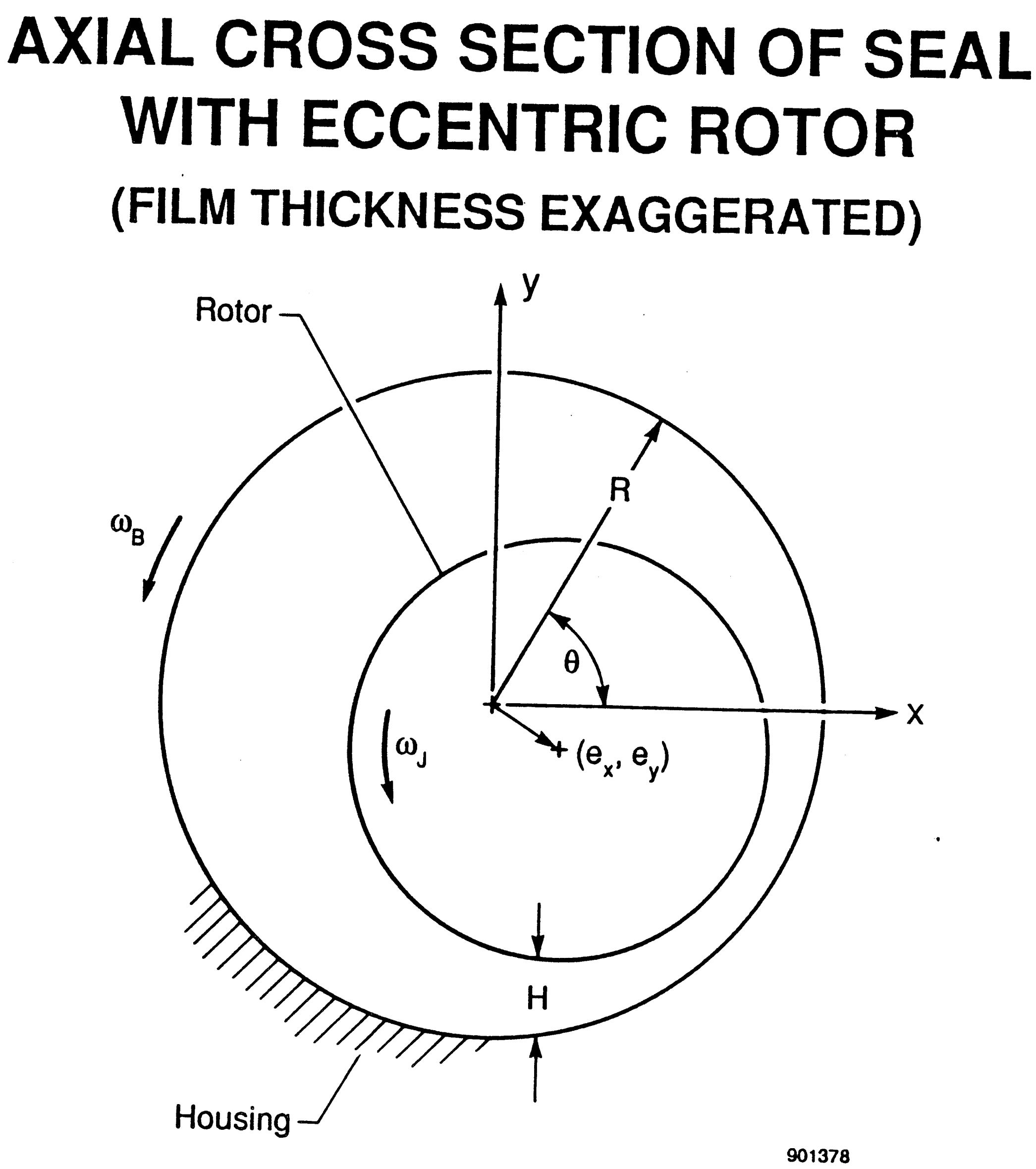

Figure 3 Axial cross-section of seal with eccentric rotor.

equations across the film[1]:

$$\begin{aligned}
\frac{(f_j Re_j + f_b Re_b)}{2} U &= -\frac{H^2}{\mu R}\frac{\partial P}{\partial \theta} + \frac{(Re_j f_j U_j + Re_b f_b U_b)}{2} \\
\frac{(f_j Re_j + f_b Re_b)}{2} V &= -\frac{H^2}{\mu}\frac{\partial P}{\partial Z}
\end{aligned} \tag{2}$$

$$\frac{1}{R}\frac{\partial}{\partial \theta}(UH) + \frac{\partial}{\partial Z}(VH) + \frac{\partial H}{\partial t} = 0 \tag{3}$$

where f_j and f_b are the friction factors relative to the housing and journal surfaces, respectively, and are functions of the Reynolds numbers relative to these surfaces as well as of their roughness. They are given by:

$$Re_i = \frac{\rho H}{\mu}\sqrt{(U-U_i)^2 + V^2} \tag{4}$$

where i=j,b, and:

$$f_i = \begin{cases} \dfrac{12}{Re_i}\,, \; Re_i \le 1000 & (laminar) \\ \dfrac{12}{Re_i}(1-3\xi^2+2\xi^3) + f_i^*(3\xi^2-2\xi^3),\; 1000 < Re_i < 3000 & \\ f_i^*\,,\; Re_i \ge 3000 & (turbulent) \end{cases} \tag{5}$$

The friction factor for turbulent flow through pipes, f^*, in equation (6) uses the curve-fit obtained by Nelson [12] to Moody's data. The transition from laminar to turbulent flow is obtained using a cubic polynomial which matches values and slopes at both ends, as reflected by equation (5). Figure 4 is a plot of the friction factor versus Reynolds number and surface roughness, while Figure 5

1 the word *film* or the term *film thickness* will be used to mean the gap of lubricant separating the rotor and housing.

$$\xi \equiv \frac{Re_l - 1000}{2000}$$

$$f_l^* = 0.001375\left[1 + \left(\frac{10^4 e_l}{H} + \frac{10^6}{4Re_l}\right)^{\frac{1}{3}}\right] \tag{6}$$

is an enlargement showing the detail of the transition region.

Under laminar flow with the friction factors equal to 12/Re, the velocities can be solved explicitly in terms of the pressure gradients:

$$u = -12h^2 \frac{\partial p}{\partial \theta} + \Lambda_j + \Lambda_b$$

$$v = -12h^2 \frac{\partial p}{\partial z} \tag{7}$$

Lubrication Background:

In the classical theory of lubrication, when the housing is stationary and the rotor wall velocity is $U_j = \omega R$, the fluid velocity components are expressed explicitly in terms of the pressure gradients:

$$U = -\frac{H^2 G_x}{12\mu R}\frac{\partial p}{\partial \theta} + \frac{\omega R}{2}, \quad V = -\frac{H^2 G_z}{12\mu}\frac{\partial p}{\partial z} \tag{8}$$

where G_x and G_z are turbulence coefficients[1] which become unity in the laminar regime. Substituting these velocity components into the continuity equation, results in the classical Reynold's equation:

$$\frac{1}{R^2}\frac{\partial}{\partial \theta}\left(H^3 G_x \frac{\partial P}{\partial \theta}\right) + \frac{\partial}{\partial Z}\left(H^3 G_z \frac{\partial P}{\partial Z}\right) = 6\mu\omega\frac{\partial H}{\partial \theta} + 12\mu\frac{\partial H}{\partial t} \tag{9}$$

Boundary conditions:

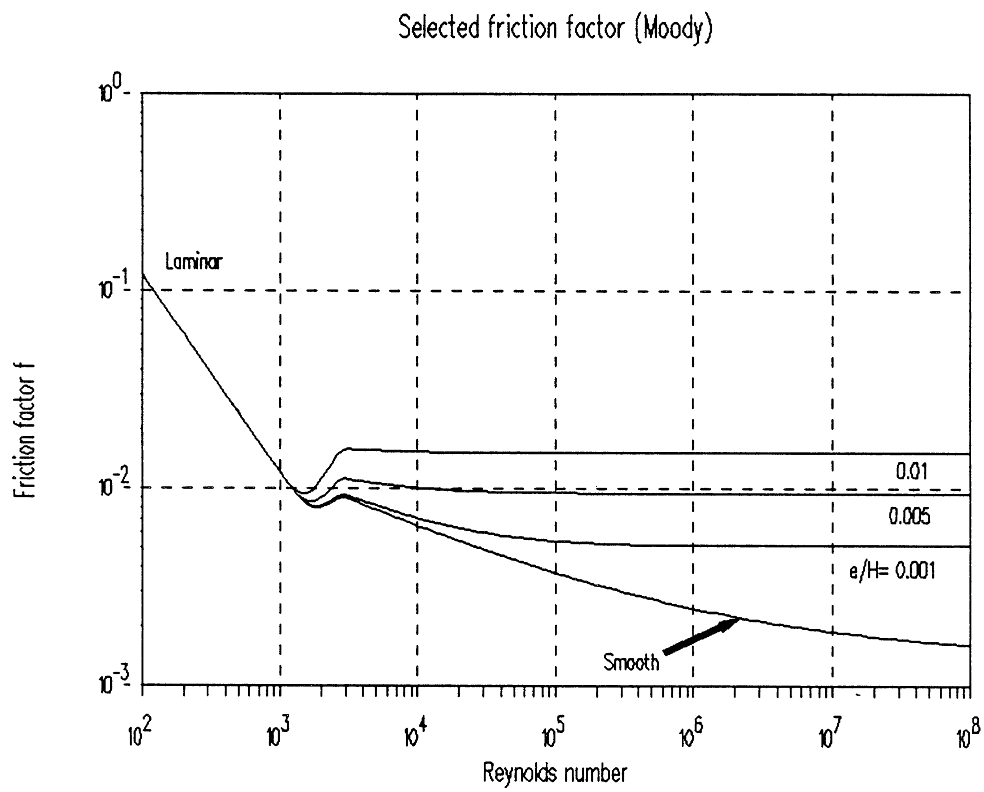

Figure 4 Friction factor versus Reynolds number

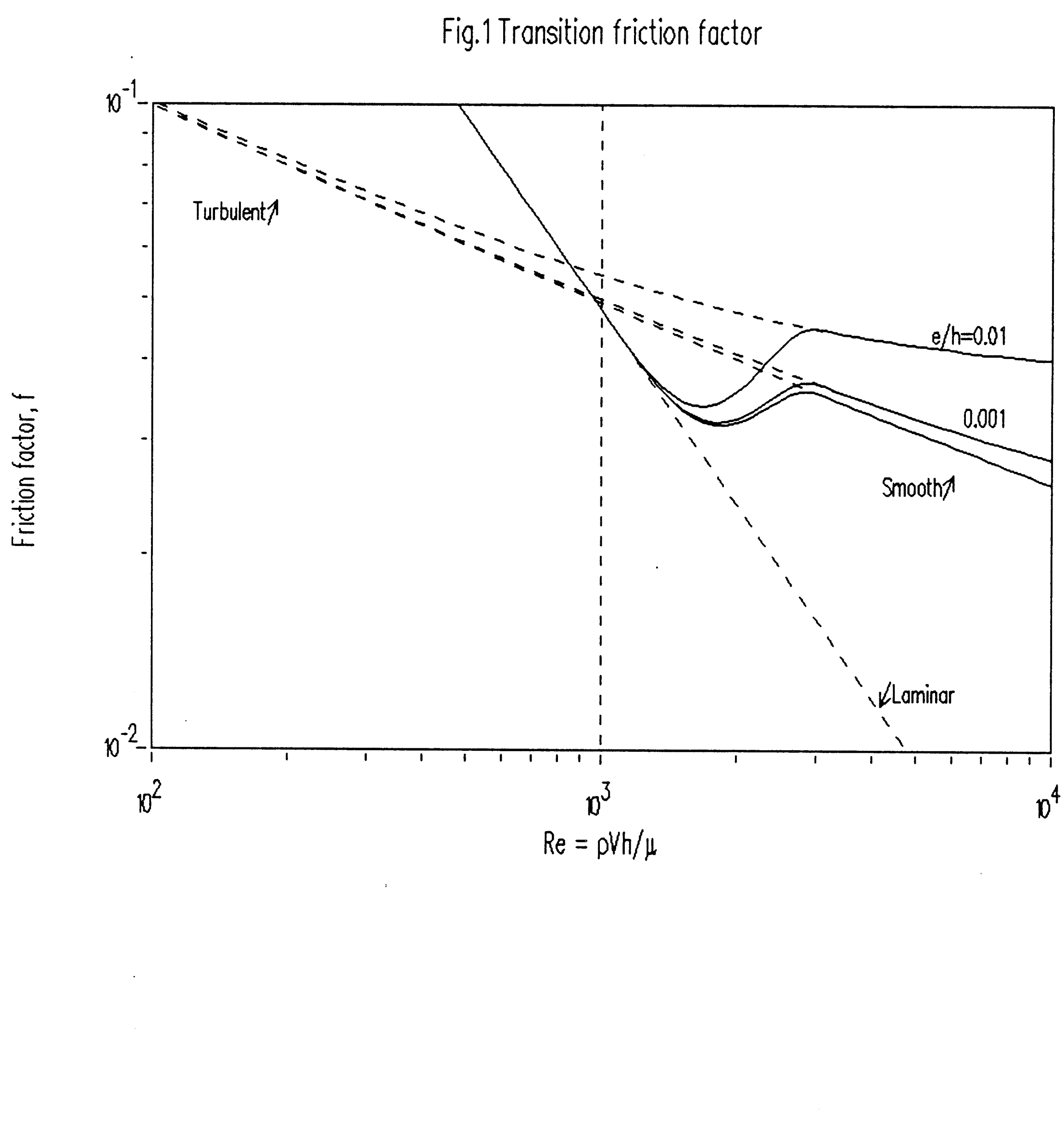

Figure 5 Detail of friction factor in transition region

Boundary conditions:

Boundary conditions on the film pressure distribution consist on prescribing either the pressure at the boundaries of the film, the flow normal to these boundaries, or a relation between these two quantities.

At the circumferential ends of the seal surface model, either the pressures are prescribed: $P(Z, \theta_s) = 0$ and $P(Z, \theta_e) = 0$,

or periodic boundary conditions exists:

$$P(Z, \theta_s) = P(Z, \theta_e) \text{ and } U(Z, \theta_s) = U(Z, \theta_e).$$

Periodic boundary conditions are used, for example, for a 360° seal, where $\theta_e = \theta_s + 2\pi$.

At the left end of the seal surface model, the pressure/flow relationship is prescribed:

$$P(-L/2,\theta) = P_l - K_e \, ½\rho V_n^2.$$

At the right end either the same relationship is used:

$$P(L/2,\theta) = P_r - K_e \, ½\rho V_n^2,$$

or the axial velocity is set to zero:

$$V(0,\theta) = 0$$

when a symmetry boundary is present at the seal mid-length.

Finally, at pocket boundaries:

$$P(Z,\theta) = P_p - K_e \, ½\rho V_n^2.$$

In all of the above relationships,

$$V_n = \begin{cases} \vec{V}\cdot\hat{n}, & \vec{V}\cdot\hat{n}>0 \\ 0, & \vec{V}\cdot\hat{n}\leq 0 \end{cases} \tag{10}$$

$$\vec{V} \equiv U\hat{e}_z + V\hat{e}_\theta$$

is the flow velocity at the entrance to the film, normal to the pressurized boundary. No pressure drop exists in the case of reverse flow (i.e., flow into the pressurized boundary).

External pressurization:

The pressure drop across the orifice supplying the pocket is given by:

$$P_s - P_p = sgn(Q_r)\,\frac{\rho}{2}\left(\frac{Q_r}{A_o C_d}\right)^2 \tag{11}$$

where A_o is the orifice area, C_d is the discharge coefficient and the flow Q_r is obtained by satisfying continuity over the pocket volume:

$$Q_r = \oint_{S_p} H\,\vec{V}\cdot\hat{n}\,dS + \int_{A_p} \frac{\partial H}{\partial t}\,dA \tag{12}$$

where A_p is the pocket area, S_p is its perimeter. Note that the contribution of **V•n̂** to this last equation may be positive or negative.

Dimensionless variables:

Using the following transformation to dimensionless variables,

$b = B\,(C^3/12\,\mu R^4)$	$\Lambda_b = 6\,\mu U_b R/(C^2 P_o)$
$f = F/(P_o R^2)$	$\Lambda_j = 6\,\mu U_j R/(C^2 P_o)$
$h = H/C$	$\epsilon = e/C$
$k = K\,(C/P_o R^2)$	$\alpha = A\,(R/C)$
$m = M/(P_o R^3)$	$\beta = B\,(R/C)$

$p = P/P_o$

$q_r = Q_r\ (12\ \mu/P_oC^3)$

$u = U\ (12\ \mu R/C^2P_o)$

$v = V\ (12\ \mu R/C^2P_o)$

$z = Z/R$

$\tau = t\ (C^2P_o/12\ \mu R^2)$

$Re^* = \rho h^3 \nabla p/\ \mu^2$

$Re_o^* = \rho C^3 P_o/(R\ \mu^2)$

$\Lambda_r = \rho C^6 P_o/(288\ A_o^2 C_d^2\ \mu^2)$

$\quad = (Re_o^*/288)\ (C^3R/A_o^2C_d^2)$

$\Lambda_e = K_e\ (Re_o^* C/288\ R),$

equations (1), (2), (3) and (4) become:

$$h = h_o - (\varepsilon_x + z\beta)\cos\theta - (\varepsilon_y - z\alpha)\sin\theta$$

$$\frac{\partial h}{\partial \tau} = -\left(\frac{\partial \varepsilon_x}{\partial \tau} + z\frac{\partial \beta}{\partial \tau}\right)\cos\theta - \left(\frac{\partial \varepsilon_y}{\partial \tau} - z\frac{\partial \alpha}{\partial \tau}\right)\sin\theta \qquad (13)$$

$$\frac{(f_j Re_j + f_b Re_b)}{2} u = -12h^2 \frac{\partial p}{\partial \theta} + (Re_j f_j \Lambda_j + Re_b f_b \Lambda_b)$$

$$\frac{(f_j Re_j + f_b Re_b)}{2} v = -12h^2 \frac{\partial p}{\partial z} \qquad (14)$$

$$\frac{\partial}{\partial \theta}(uh) + \frac{\partial}{\partial z}(vh) + \frac{\partial h}{\partial \tau} = 0 \qquad (15)$$

$$Re_i = \frac{Re_o^* h}{12}\sqrt{(u - 2\Lambda_i)^2 + v^2}, \quad i = j, b \qquad (16)$$

Equations (5) and (6) remained unaltered, as they were already dimensionless.

The dimensionless form of the boundary conditions now become:

At the circumferential ends, either:

$p(z, \theta_s) = 0$ and $p(z, \theta_e) = 0$

or:

$p(z, \theta_s) = p(z, \theta_e)$ and $u(z, \theta_s) = u(z, \theta_e)$.

when periodic boundary conditions are present.

At the left end:

$$p(-L/D,\theta) = p_l - \Lambda_e v_n^2,$$

and at the right end either:

$$p(\ L/D,\theta) = p_r - \Lambda_e v_n^2$$

or:

$$v(0,\theta) = 0.$$

At pocket boundaries: $p(z,\theta) = p_p - \Lambda_e v_n^2$

where:

$$v_n = \begin{cases} \boldsymbol{v}\cdot\hat{\boldsymbol{n}}, & \boldsymbol{v}\cdot\hat{\boldsymbol{n}} > 0 \\ 0, & \boldsymbol{v}\cdot\hat{\boldsymbol{n}} \le 0 \end{cases} \tag{17}$$

$$\boldsymbol{v} \equiv u\,\hat{\boldsymbol{e}}_z + v\,\hat{\boldsymbol{e}}_\theta$$

Equations (11) and (12) governing the external pressurization become:

$$p_s - p_p = sgn(q_r)\,\Lambda_r q_r^2 \tag{18}$$

$$q_r = \oint_{S_p} h\ \boldsymbol{v}\cdot\hat{\boldsymbol{n}}\ ds + \int_{A_p} \frac{\partial h}{\partial \tau}\ d\theta\, dz \tag{19}$$

2.2 Solution of film pressures

Discretization of the seal surface is done by using a rectangular grid, with **M** lines in the axial direction and **N** lines in the circumferential direction. The grid lines are separated by variable increments. The pressure distribution is represented by discrete values at the grid points located at the intersections of the grid lines. There must be grid lines coincident with the boundaries of the seal surface ($Z = \pm L/2$, $\theta = \theta_s$, $\theta = \theta_e$) and with the pocket boundaries. Using the cell method [3], a control area or cell is centered at each grid point and extending half way to the neighboring grid lines, as shown by the shaded area in Figure 6. The grid points are noted by the solid circles and have grid coordinates i,j. The film thickness is evaluated at the corners of the cell (denoted by the shaded circles marked h_1, h_2, h_3, and h_4) located at the geometric centers of the rectangles formed by the grid lines. This staggered configuration allows a discontinuous film thickness to be treated, as occurs, for example in a seal with a Rayleigh-step. Circumferential and axial components of velocity are also associated with each of the four cell corners.

Using the divergence theorem, the continuity equation may be integrated over the cell to give:

$$-\oint_{S_c} \boldsymbol{v}\cdot\hat{\boldsymbol{n}}\; dS = \int_{A_c} \frac{\partial h}{\partial \tau}\, dA \tag{20}$$

where A_c and S_c are the cell area and perimeters, respectively. The left hand side of the above equation is the sum of the flows out of the cell while the right hand side is the rate of change of the cell volume. The finite-difference form of this equation is:

$$\begin{aligned} F_{i,j} = {} & \frac{\Delta z_i}{2}\left(u_1 h_1 - u_4 h_4\right) + \frac{\Delta z_{i-1}}{2}\left(u_2 h_2 - u_3 h_3\right) + \\ & + \frac{\Delta \theta_j}{2}\left(v_1 h_1 - v_2 h_2\right) + \frac{\Delta \theta_{j-1}}{2}\left(v_4 h_4 - v_3 h_3\right) - \\ & - \frac{1}{4}\,\frac{\partial h_{i,j}}{\partial \tau}\left(\Delta z_i + \Delta z_{i-1}\right)\left(\Delta \theta_j + \Delta \theta_{j-1}\right) = 0 \end{aligned} \tag{21}$$

where $F_{i,j}$ is the error in satisfying continuity of flow in the cell centered at i,j. Although the time rate of change of film thickness has been evaluated at the center of the cell, it could have alternatively been evaluated at each of the four cell corners.

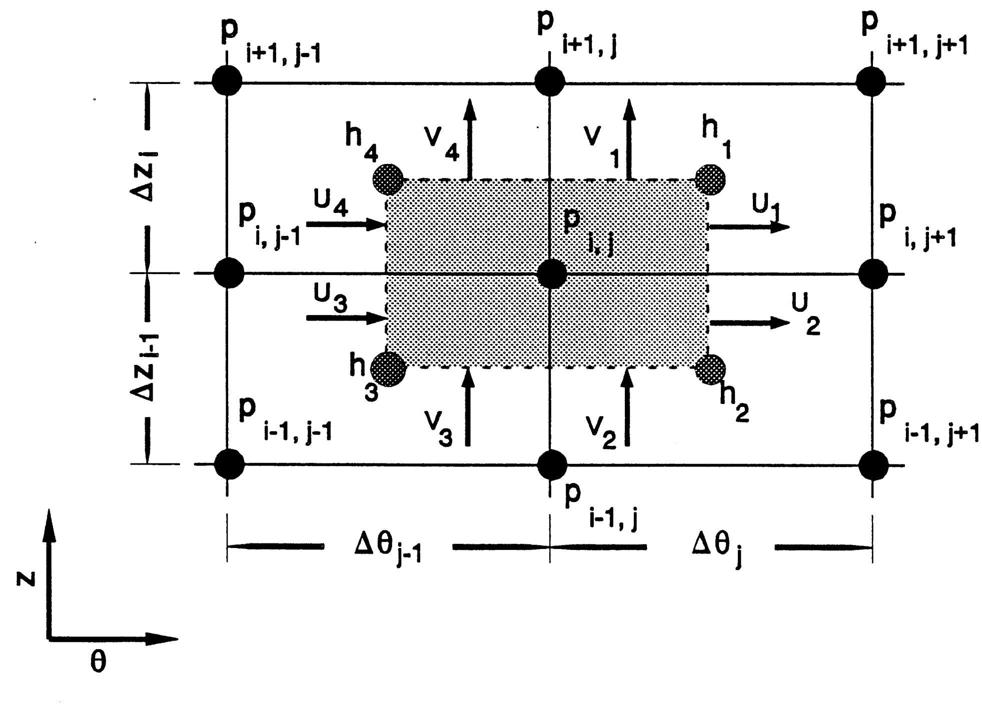

Figure 6 Flow control area about grid point i,j.

When the grid point falls on a pressurized boundary, such as a pocket or seal end, the film pressure error is:

$$
\begin{aligned}
F_{i,j} &= p_b - p_{i,j} - \Lambda_e \max(0, v_n)^2 = 0 \\
v_n &= \frac{\Sigma_{i,j}}{s_b h_{i,j}}
\end{aligned}
\tag{22}
$$

where p_b is the dimensionless boundary pressure[2], v_n is the mean velocity of the flow that crosses the portion of the boundary perimeter that intersects the cell, and $\Sigma_{i,j}$ represents the sum of the appropriate terms in equation (21) contributing to the cell flow. Figure 7 shows an example of the cell i,j located at the right bottom corner of a pocket. In this case, the mean velocity would be evaluated as:

$$
\begin{aligned}
v_n = \Bigg[& \frac{\Delta z_i}{2}(u_1 h_1) + \frac{\Delta z_{i-1}}{2}(u_2 h_2 - u_3 h_3) + \frac{\Delta\theta_j}{2}(v_1 h_1 - v_2 h_2) - \frac{\Delta\theta_{j-1}}{2}(v_3 h_3) - \\
& - \frac{\partial h_{i,j}}{\partial \tau} \frac{(\Delta z_i + \Delta z_{i-1})\Delta\theta_j + \Delta z_{i-1}\Delta\theta_{j-1}}{4} \Bigg] \div \left[\frac{(\Delta\theta_{j-1} + \Delta z_i) h_{i,j}}{2} \right]
\end{aligned}
\tag{23}
$$

Equations (21) and (22) represent the finite-difference form of the continuity equation that must be solved for the pressures. The eight components of velocity used in these equations are functions of the nine pressures at or neighboring grid point i,j, and are evaluated as described in section 2.3. Following the procedure described in reference 1, these highly nonlinear equations can be solved using the Newton-Raphson iteration method [14]. The procedure is started with an initially guessed or previously calculated pressure.

---

2 P_l/P_o, P_r/P_o or P_p/P_o.

distribution, $p_{i,j}$. The error function F_{ij} is then linearized about this guess in order to obtain a better approximation to the pressures $p_{i,j}^{new}$:

$$F_{ij} + \sum_{\substack{k=i-1,i+1\\ l=j-1,j+1}} \frac{\partial F_{ij}}{\partial P_{kl}} \left(P_{kl}^{new} - P_{kl} \right) = 0 \tag{24}$$

where a forward difference or a central difference may optionally be used to numerically evaluate the partial derivatives. Pressures without the superscript **new** relate to the previous or "old" approximation. If we introduce the column vector $\{p_j^{new}\}$ as the **M** new pressures at the jth column of grid points, Equation (24) may be written:

$$[C^j]\{p_j^{new}\} + [E^j]\{p_{j-1}^{new}\} + [D^j]\{p_{j+1}^{new}\} = \{R^j\} \quad , \tag{25}$$

where $[C^j]$, $[E^j]$ and $[D^j]$ are tri-diagonal matrices whose interior elements are:

$$C^j_{i,i+k} = \frac{\partial F_{ij}}{\partial p_{i+k,j}} \ , \quad E^j_{i,i+k} = \frac{\partial F_{ij}}{\partial p_{i+k,j-1}} \ , \quad D^j_{i,i+k} = \frac{\partial F_{ij}}{\partial p_{i+k,j+1}} \ , \quad k = -1,0,1 \ ; \quad i = 2,\ldots,M-$$

The interior elements of the column vector $\{R^j\}$ are:

$$R_i^j = \sum_{k=-1}^{1} \left(C^j_{i,i+k} p_{i+k,j} + E^j_{i,i+k} p_{i+k,j-1} + D^j_{i,i+k} p_{i+k,j+1} \right) - F_{ij} \quad .$$

The set of linear equations (26) that result for the next guess of pressure distribution is in a form suitable for solution by the column method which is described in detail in References 3 and 4. This method makes use of the banded nature of the equations in order to minimize computer time.

2.3 Solution of flow velocity

The momentum equations (14) are used in order to evaluate the velocity components from the pressure gradients. These equations may be rewritten

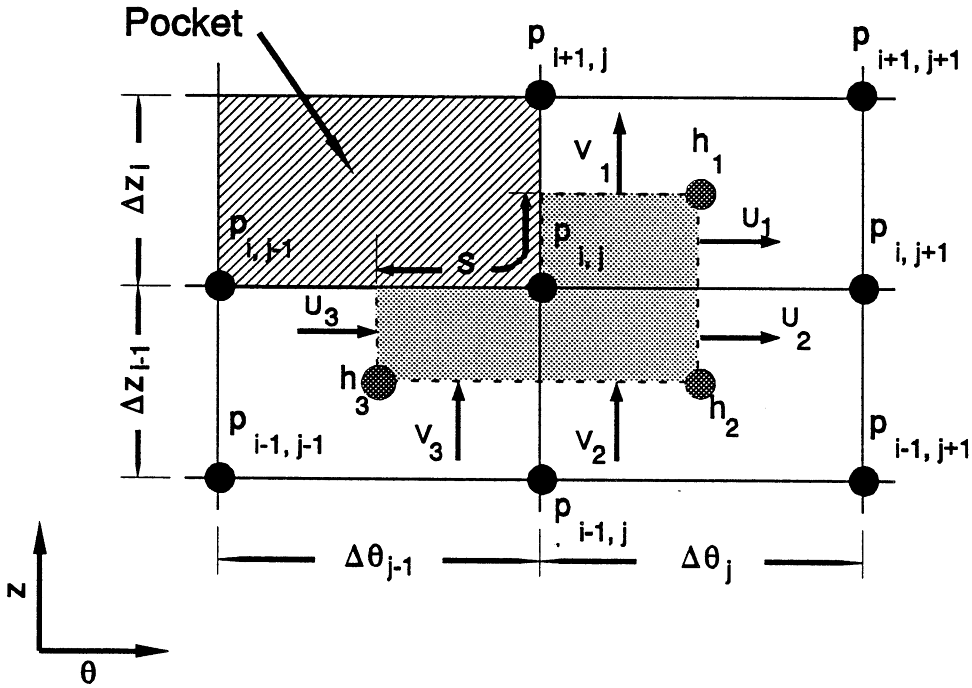

Figure 7 Example of cell at corner of pocket.

in the generic form:

$$G_u\left[\frac{\partial p}{\partial \theta}, u, v\right] \equiv \frac{f_j Re_j + f_b Re_b}{2} u + 12h^2 \frac{\partial p}{\partial \theta} - \left(Re_j f_j \Lambda_j + Re_b f_b \Lambda_b\right) = 0,$$
$$G_v\left[\frac{\partial p}{\partial z}, u, v\right] \equiv \frac{f_j Re_j + f_b Re_b}{2} v + 12h^2 \frac{\partial p}{\partial z} = 0, \tag{26}$$

where the Reynolds numbers used to evaluate the friction factors are based on the *magnitude* of the local fluid velocity relative to each surface:

$$Re_j = \frac{Re_o^* h}{12}\sqrt{(u-2\Lambda_j)^2 + v^2},$$
$$Re_b = \frac{Re_o^* h}{12}\sqrt{(u-2\Lambda_b)^2 + v^2}, \tag{27}$$

The dependence of the friction factors on velocity components orthogonal to each momentum direction couples the two momentum equations. Figure 8 is a schematic of the rectangular region between axial grid lines i and i+1 and circumferential grid lines j and j+1. In order to preserve continuity, it is essential that the same equation be used to evaluate the velocity components for adjacent cells. That is, the velocity u_1 out of the shaded cell centered at i,j must have the same value as the velocity u_4 into the cell centered at i,j+1. This value is designated as u^- in the figure. Similarly, the velocity v_1 out of the cell i,j must be the same as v_2 into the cell at i+1,j, and is designated as v^-. This is achieved by using the average of the two corresponding orthogonal components. Thus, the component u^- is determined by the u-momentum equation:

$$G_u\left[\frac{p_{i,j+1} - p_{i,j}}{\Delta\theta_j},\ u^-,\ \frac{v^- + v^+}{2}\right] = 0 \tag{28}$$

while the component v^- is determined by the v-momentum equation:

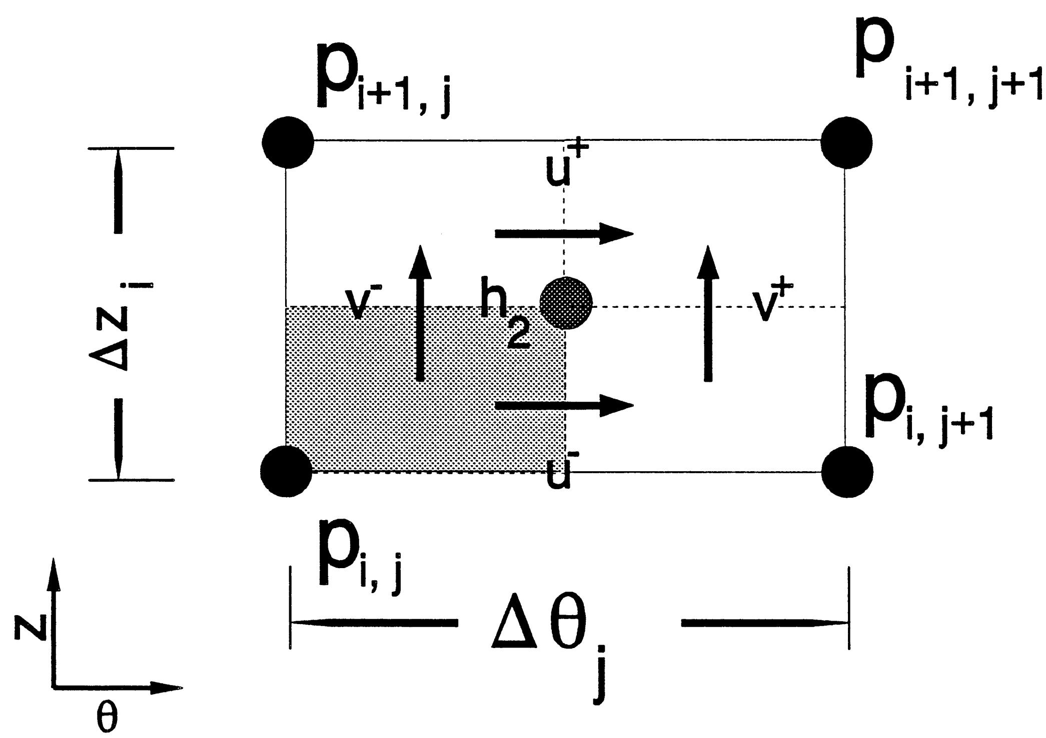

Figure 8 Schematic of rectangular region between grid lines.

$$G_v\left[\frac{p_{i+1,j}-p_{i,j}}{\Delta z_i},\ \frac{u^- + u^+}{2},\ v^-\right] = 0 \tag{29}$$

Similarly, u^+ and v^+ are determined by:

$$\begin{aligned} G_u\left[\frac{p_{i+1,j+1}-p_{i+1,j}}{\Delta \theta_j}, u^+, \frac{v^- + v^+}{2}\right] &= 0 \\ G_v\left[\frac{p_{i+1,j+1}-p_{i,j+1}}{\Delta z_i}, \frac{u^- + u^+}{2}, v^+\right] &= 0 \end{aligned} \tag{30}$$

Equations (28), (29) and (30) are four coupled equations that determine the velocity components from the four pressures at the corners of the rectangle between grid lines and must be solved simultaneously. This is done using an inner Newton-Raphson iteration loop. By performing the differentiation of the error functions (Gu, Gv, ...) with respect to the four unknown velocities, analytically instead of numerically, significant computer time is saved. If the velocities have not been previously calculated initial guesses may be obtained from equations (7) assuming laminar flow. Once the iterations for the velocities have converged, their values are saved to provide a good starting guess for the next time they must be calculated.

One simplification is possible by assuming that the friction factors are constant within the rectangular region and the Reynolds numbers are based on the averaged flow velocity components, $\frac{1}{2}(u^- + u^+)$ and $\frac{1}{2}(v^- + v^+)$. Although this does not uncouple the four equations, it requires less number of evaluations of the square root in equation (16). Since this assumption saves some computer time without introducing significant errors, it was chosen as the default program option (**IFRIC=3**). However, occasionally when the grid is not very fine and the pressure gradients vary rapidly, the iterations will diverge and the more rigorous formulation, which uses distinct friction factors for each of the four momentum equations, should be used with the **IFRIC=4** option.

If the surfaces are smooth and the housing is stationary so that the continuity equation takes the form of equation (9), the simpler formulation described in detail in Reference 1 may be used by selecting the option **IFRIC = 0**, resulting in significant reduction in computer time.

2.4 Fluid film load, moment and torque

The forces and moments on the rotor generated by the fluid film pressure distribution are obtained by integration of the pressure distribution over the cylindrical seal surface:

$$\begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} = \int_{-L}^{L} \int_{\theta_s}^{\theta_e} P \begin{Bmatrix} \cos\theta \\ \sin\theta \\ -Z\sin\theta \\ Z\cos\theta \end{Bmatrix} R\,d\theta\,dZ \tag{31}$$

The dimensionless form this equation is written:

$$\begin{Bmatrix} f_x \\ f_y \\ m_x \\ m_y \end{Bmatrix} = \int_{-\frac{L}{D}}^{\frac{L}{D}} \int_{\theta_s}^{\theta_e} p \begin{Bmatrix} \cos\theta \\ \sin\theta \\ -z\sin\theta \\ z\cos\theta \end{Bmatrix} d\theta\,dz \tag{32}$$

The differential of torque transmitted from the housing to the rotor is given by the cross product of the position vector $\vec{\mathbf{r}}$ and the shear traction vector acting on the housing $\vec{\mathbf{t}}$:

For laminar regime, $f_j Re_j = f_b Re_b = 12$, and the equation simplifies to:

$$\vec{T} = T\hat{\mathbf{e}}_z = \iint_{A_f} \vec{r} \times \vec{t} \; dA$$

$$= R \iint_{A_f} \hat{\mathbf{e}}_r \times (\bar{\tau} \bullet \hat{\mathbf{e}}_r) \; dA \tag{33}$$

$$T = \frac{P_o R^2}{2C_o} \iint_{A_f} \{ h\frac{\partial p}{\partial \theta} - \frac{f_j R_j (u - 2\Lambda_j) - f_b R_b (u - 2\Lambda_b)}{72h} \} \; d\theta \, dZ$$

$$T = \frac{P_o R^2}{2C_o} \iint_{A_f} \{ h\frac{\partial p}{\partial \theta} - \frac{\Lambda_j - \Lambda_b}{3h} \} \; d\theta \, dZ \tag{34}$$

The power loss due to the difference in velocities across the two surfaces is obtained by doting this torque with the relative velocity:

$$P = T(\omega_b - \omega_j)$$

$$= \frac{P_o R^2}{2C_o} \iint_{A_f} \{ h\frac{\partial p}{\partial \theta} - \frac{f_j R_j (u - 2\Lambda_j) - f_b R_b (u - 2\Lambda_b)}{72h} \} \; (\Lambda_j - \Lambda_b) \; d\theta \, dZ \tag{35}$$

2.5 Stiffness and damping coefficients

Defining $\vec{\mathbf{W}}$ to be a generalized vector of forces and moments generated by the fluid film pressure and $\vec{\mathbf{r}}$ to be a generalized vector of lateral and angular displacements:

$$\boldsymbol{W} = \begin{Bmatrix} f_x \\ f_y \\ m_x \\ m_y \end{Bmatrix} \quad \boldsymbol{r} = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \alpha \\ \beta \end{Bmatrix} \quad \dot{\boldsymbol{r}} = \frac{\partial}{\partial \tau} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \alpha \\ \beta \end{Bmatrix} \tag{36}$$

the matrices of stiffness and damping coefficients can be written:

$$k_{ij} = -\frac{\partial W_i}{\partial r_j} \qquad b_{ij} = -\frac{\partial W_i}{\partial \dot{r}_j} \tag{37}$$

where the subscripts i and j range over x, y, α and β. These coefficients are evaluated by numerical differentiation of **W**, using a forward difference. For example:

$$K_{y\alpha} = \frac{F_y(\epsilon_x,\, \epsilon_y,\, \alpha+\delta,\, \beta) - F_y(\epsilon_x,\, \epsilon_y,\, \alpha,\, \beta)}{\delta} \tag{38}$$

2.6 Solution of rotor position and pocket pressures

If the rotor position is specified, equation (36) is used to solve for the fluid film forces and moments in terms of the calculated pressure field. Similarly, if the pocket pressures are specified, equation (11) is used to solve for the orifice size in terms of the supply pressure and calculated pocket flow.

On the other hand, if externally applied loads and moments on the rotor ($\mathbf{f_{xg}}$, $\mathbf{f_{yg}}$, $\mathbf{m_{xg}}$ **and** $\mathbf{m_{yg}}$) are specified they must be balanced by the fluid film forces to maintain static equilibrium. Similarly, once the orifice size is specified, equation

(11) must be satisfied by the pressure in each pocket. The global set of equations that must be satisfied by the rotor displacements and pocket pressures are:

$$
\begin{aligned}
f_x(r) &= -f_{xg} \\
f_y(r) &= -f_{yg} \\
m_x(r) &= -m_{xg} \\
m_y(r) &= -m_{yg} \\
p_s - p_{p1} &= sng(q_{r1})\,\Lambda_{r1}(q_{r1})^2, \quad \text{for pocket } 1, \\
p_s - p_{p2} &= sng(q_{r2})\,\Lambda_{r2}(q_{r2})^2, \quad \text{for pocket } 2, \text{ etc.}
\end{aligned}
\tag{39}
$$

The vector $\vec{r}$ can now be redefined to include the pocket pressures and a generalized vector of errors in forces, moments and pocket pressures $\vec{W}_e$ can be defined:

$$
r = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \alpha \\ \beta \\ p_{p1} \\ p_{p2} \\ \vdots \end{Bmatrix} \qquad W_e = \begin{Bmatrix} f_x + f_{xg} \\ f_y + f_{yg} \\ m_x + m_{xg} \\ m_y + m_{yg} \\ p_s - p_{p1} - sgn(q_{r1})\,\Lambda_{r2}(q_{r1})^2 \\ p_s - p_{p2} - sgn(q_{r2})\,\Lambda_{r2}(q_{r2})^2 \\ \vdots \end{Bmatrix}
\tag{40}
$$

Solution of the global equations is performed by Newton-Raphson iterations, as follows:

$$
W_e + \left[\frac{\partial W_e}{\partial r}\right](\, r^{new} - r\,) = 0
\tag{41}
$$

where, as before, the superscript **new** indicates the newer values of the vector $\vec{r}$.

3.0 PROGRAM USAGE AND INPUT DESCRIPTION

3.1 Program Usage

Using an editor, the user prepares an input file named ICYL.INP, as described in section **3.2**.

Execution is started by entering the command:

ICYL1

The program will write iteration diagnostics to the screen to show the progress of the calculations. Screen output need not be saved, since iteration diagnostics are also written to a file as described below.

Once execution is finished:

The user may review the results by editing, browsing or printing the output file, called *fname*.out where *fname* is the filename from the input file namelist variable 'OUTFIL'. Other files created by the execution are:

fname.itr Iteration history diagnostics. Also contains all screen display output.

fname.hpf Pressure, film thickness and velocity distributions for subsequent plotting by program PLOT3D as described in section **4.2**.

fname.888 Binary file storing the pressure and velocity distributions. This file may be used to restart calculations by a subsequent run. See description of variable **IREADP.**

fname.999 Binary file of stored pressure and velocity distributions to be read in current run. This file is created by copying a *fname*.888 file from previous run. See description of variable **IREADP**.

3.2 Input description

All the input is in NAMELIST format. The input for each case to be run starts with "&INPUTS" and ends with a "/". In between, the variables and arrays are assigned their values. Variable assignments are delimited by blanks or commas. The namelist field must be kept within columns 2 and 80 of the file. Text outside of the namelist fields is ignored.

Additional cases may be specified following each other as desired. The program will read a namelist &INPUTS for each case to be run. The program will continue to loop, reading the namelist for a case and executing it, until it reaches the end of file or until a namelist with ISTOP = 1 is read. The case with ISTOP = 1 will not be executed. Any variables not specified within a namelist will retain the value from the previous case. Variables not specified on the first case will have the default value.

In order to input arrays, either the specific indices of the elements are specified or the elements are entered in order. For example, the following three specifications are equivalent:

```
M1(1)=3, M1(2)=6, M1(3)=3, M1(4)=6,

M1= 3,   M1(2)=6, 3, 6,

M1= 3, 6, 3, 6,
```

For arrays with two indices, the first index can be assumed to increase by one when more than one element is specified. The second index should always be specified. For example, the following two specifications are equivalent:

DELTA(1,3) = 0.001, DELTA(2,3) = 0.002, DELTA(3,3) = 0.003,

DELTA(1,3) = 0.001, 0.002, 0.003,

It is recommended that array specifications be placed at the end of the namelist field. This avoids a problem with the Microsoft compiler which occasionally caused a FORTRAN namelist read-error when the reverse order was used.

Table 1 Units for variables

Symbol		English units	SI units
L	length	inches	m
F	force	Lb_f	N
T	time	sec	sec

The units of the input variables are indicated in brackets after their description, e.g., [F/L^2], in terms of force units [F], length units [L], and time units [T]. Table 1 gives the values of these units depending on the system of units being used. This is followed by any limits and default values.

INPUT VARIABLES Description

TITLE	Character string, consisting of any string of up to 64 characters. (Default=Default input values for the ICYL program)
	For example: TITLE='Test of program ICYL'
OUTFIL	Filename of output file (no extension) (Default='ICYL')
UNITS='ENGLISH'	Labeling in output file will use English units (Default)
='SI'	Labeling in output file will use SI units
	Note that the program calculations are not affected by this input, since a consistent set of units is used.

GEOMETRY DESCRIPTION:

CREF	Reference clearance (i.e., at concentric position) [L] (0 < CREF) (Default = 0)*
RADIUS	Radius of cylindrical seal surface [L] (0 < RADIUS) (Default = 0)*

---

* Variables which default to zero but must have a non-zero value are required input for the 1st case to be run.

LENGTH Length of cylindrical seal surface [L] (0 < LENGTH) (Default = 0)*

ROUGHJ Roughness of rotor surface [L] ($0 \geq$ ROUGHJ) (Default = 0)

ROUGHB Roughness of housing surface [L] ($0 \geq$ ROUGHB) (Default = 0)

ISYM=0 For modeling the full seal. Boundary at $z = L/2$ ($i = M$) has a specified pressure. (Default)

=1 For modeling half of the seal. Boundary at $z = L/2$ ($i = M$) is a seal line of symmetry.

IPER=0 For specified pressure boundary conditions at the circumferential start and end of the model.

=1 For modeling periodic boundary conditions at the circumferential start and end of the model. See warning in description of variable PCAV. (Default)

TS,TE Circumferential start and end of the model (Degrees). (Defaults: TS = 0, TE = 360). (TS < TE)

FLUID DESCRIPTION:

RHO Lubricant mass density [$F\text{-}T^2/L^2$] ($0 \leq$ RHO) (Default = 0)*

XMU Lubricant-viscosity [$F\text{-}T/L^2$] (0 < XMU) (Default = 0)*

OPERATING & BOUNDARY CONDITIONS:

RPMJ Speed of rotor surface [RPM] ($0 \leq$ RPMJ) (Default = 0)

RPMB Speed of housing surface [RPM] ($0 \leq$ RPMB) (Default = 0)

PCAV Lubricant cavitation vapor pressure. When a periodic boundary condition (IPER=1) is used, PCAV should be set equal to a large negative number, such that any of the resulting film pressures is larger than PCAV. This restriction is because although cavitation is treated properly with the Swift-Steiber condition at the trailing end, film reformation problem is not performed. When IPER=1, the program will first calculate the pressure distribution and then set any pressure less than PCAV equal to it. [F/L^2] (Default = 0)

PL1,PR1 Boundary pressures at left and right ends, respectively, at the start of the model (Θ = TS). [F/L^2] (Default = 0)

PL2,PR2 Boundary pressures at left and right ends, respectively, at the end of the model (Θ = TE). These values are only used when IPER=0. [F/L^2] (Default = 0)

EX,EY,ALFA,BETA Radial and angular displacements of rotor with respect to the housing. EX, EY are components of eccentricity ratio and are therefore dimensionless. The eccentricity ratio is the eccentricity of the rotor relative to the housing at Z = 0 divided by the reference clearance, CREF. ALFA, BETA are the components of the rotation of the rotor relative to the housing, scaled by (2*LENGTH/CREF), so that rotor to housing contact occurs when $ALFA^2 + BETA^2$ is unity.

All four quantities default to 0 and are restricted to:

$$EX^2 + EY^2 + ALFA^2 + BETA^2 < 1$$

It is recommended that non-zero values of radial and/or angular displacements be specified as initial guesses when the external forces and/or moments are specified.

ALFA and BETA must be zero if ISYM=1, since that is the only way that the pressure distribution will be symmetric about the Z=0 plane.

FXG,FYG, MXG,MYG

External forces and moments applied to the rotor. (All four quantities default to -999. indicating that their value was not specified). If not specified the program will assume that the analysis is to be performed at the rotor position specified by EX,EY,ALFA,BETA. If specified, the program will perform iterations to find the rotor position. As explained in more detail below, the user may specify the radial position independently of the angular position.

If FXG,FYG are specified, the program will calculate the radial rotor position, using the input values of EX,EY as initial guesses while retaining the specified angular rotor position. Specification of FXG alone assumes that FYG is zero and vice versa.

Similarly, if MXG,MYG are specified, the program will calculate the angular position using the input values of ALFA and BETA as initial guesses while retaining the specified radial rotor position. Specification of MXG alone assumes that MYG is zero and vice versa.

If all four variables (FXG,FYG,MXG,MYG) are specified, the program will calculate the rotor position using the input values of EX,EY,ALFA and BETA as initial guesses.

MXG and MYG must not be specified (or set equal to their default value of -999.) if ISYM=1, since the moments resulting from a pressure distribution that is symmetric about the Z=0 plane are zero.

EXD,EYD, ALFAD,BETAD Radial and angular velocities of rotor with respect to housing. The program calculates the damping coefficients internally by incrementing these velocities by TOL(1) and dividing the resulting perturbations in the forces and moments by this increment. These quantities are rarely used for steady state calculations, and should be left equal to zero. They are described in the input for calculating performance at prescribed *finite* rotor velocities. [T^{-1}] (Default = 0)

POCKET PARAMETERS:

NPOCK Number of pockets (Default = 0) ($0 \leq$ NPOCK ≤ 20 and $1 \leq k \leq$ NPOCK)

M1(k),M2(k) Axial integer coordinates at the start and end of pockets. (Default = 0) ($1 \leq M1(k) \leq M2(k) \leq M$)

N1(k),N2(k) Circumferential integer coordinates at the start and end of pockets. (Default = 0) ($1 \leq N1(k) \leq N2(k) \leq N$)

PPOCK(k) Pocket pressure. [F/L^2] (Default = 0)

PSUP Supply pressure [F/L^2] In case both rotor and housing speeds are zero, a positive value should be prescribed for PSUP even if no pockets are specified, since the program will use this value for the internal pressure scale. (Default = 0)*

DORIF Orifice diameter. Set equal to zero to calculate its value based on specified pocket pressure. If DORIF is non-zero, PPOCK(k) will only be used as an initial estimate of the k-th pocket pressures) [L] (Default = 0) ($0 \leq$ DORIF)

CD Coefficient of discharge for flow through orifice (Default = 0.6) ($0 <$ CD)

VARIABLE GRID SPECIFICATIONS

M,N Grid mesh size in the axial and circumferential directions. (Defaults: M = 5, N = 11) ($2 \leq M \leq 91$, $2 \leq N \leq 201$)

DZT(i) Array of axial coordinate increments (M-1 values). If DZT(1) is not specified or zero, the program will use an equal spacing axially. (Default = 0) ($1 \leq i \leq N-1$)

DTH(j) Array of circumferential coordinate increments (N-1 values). If DTH(1) is not specified or zero, the program will use an equal spacing circumferentially. (Default = 0) ($1 \leq j \leq M-1$)

Only the ratios between the coordinate increments is used, since the dimensions of the seal are specified separately by the variables LENGTH, TS and TE. For this reason, the units used for the increments are irrelevant.

ARBITRARY FILM & PRESSURE SPECIFICATIONS

A number of rectangular regions may be specified in which additional clearance or a fixed pressure is specified. Figure 9 illustrates the variables describing the k-th region ($1 \le k \le 40$).

I1F(k),I2F(k) Axial integer coordinates at the start and end of the k-th region (Default = 0)

J1F(k),J2F(k) Circumferential integer coordinates at the start and end of the k-th region (Default = 0)

DELTA(1,k) Region depth for: I1F(k) < i < I2F(k), J1F(k) < j < j2F(k) (Default = 0)

DELTA(2,k) Additional depth at i = I2F(k). (Use this for axial taper). (Default = 0)

DELTA(3,k) Additional depth* at j = J2F(k). (Use this for circumferential taper) (Default = 0)

DELTA(4,k) Region preload ratio. This ratio is defined as the decrease in film thickness at the center of the region divided by the reference clearance (CREF). Normally a preloaded sector will extend across the seal length with: I1F=1,I2F=M. (Default = 0)

DELTA(5,k) Specified constant pressure within the region. (Do not use this for an externally pressurized pocket: instead use PPOCK with DORIF = 0). A value of -999. means that the pressure

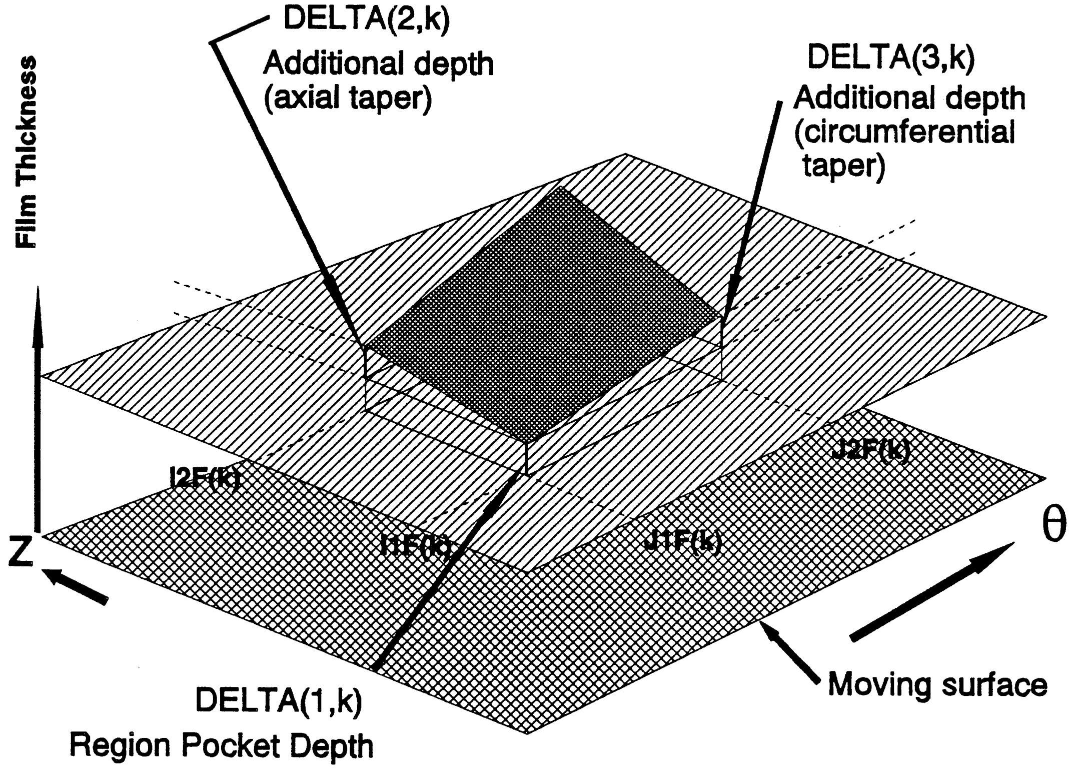

Figure 9 Arbitrary film thickness specification

is not specified in the k-th region. (Default = -999.) [F/L^2]

Positive values of DELTA(1,k), DELTA(2,k) and DELTA(3,k) indicate increased film thickness beyond CREF, while a positive value of DELTA(4,k) indicates a decrease in film thickness.

If I2F(k) = I1F(k) the region is a circumferential line, if J2F(k) = J1F(k) the region is a axial line, and If both are true the specification is valid only at a grid point. If I2F(k) = 0 it is assumed equal to I1F(k). If J2F(k) = 0 it is assumed equal to J1F(k).

PROGRAM CONTROLS

There are three nested iteration loops:

1. The inner-most iteration loop is for velocity components within each of the four corners of a cell.

2. The middle iteration loop is for the pressure distribution.

3. The outer iteration loop is to calculate rotor position and pocket pressures.

There are three controls for each of the iteration loops (k = 1,2,3):

ECR(k) Error criteria that must be achieved before iteration stops. (Defaults = 10^{-10}, 10^{-8} and 10^{-6})

NIT(k) Maximum number of iterations (Defaults = 21, 21, 10)

TOL(k) Tolerance used to evaluate partial derivative of error with respect to the unknown variables. TOL(1) is not used since the differentiations are performed analytically for the inner-most iteration loop. (Defaults = 0, -10^{-6} and 10^{-4})

If $|P_{i,j}| >$ 1.e-6, $|TOL(2)*P_{i,j}|$ is used, else $|TOL(2)|$ is used. Use a positive value for a forward difference or a negative value for a central difference.

MAXDIT Maximum number of consecutive diverging iterations allowed before the program stops (Defaults to 1).

IFRICT= 3	New analysis (Rough, based on Moody formula) (Default)
= 0	Previous analysis (Smooth,based on Ng-Elrod Linearized Turbulence). This friction model has been used successfully for a number of years at MTI. Although it may not account for surface roughness effects, it is accurate and will reduce computation time significantly. Do not use this with inertia pressure drop from pressurized seal ends (i.e., XKE>0 and non-zero PL1 or PR1).
= 4	Refined new analysis (Under this option, the program will average the orthogonal components of velocity).
XKE	Film entrance loss coefficient (dimensionless). This coefficient expresses the pressure loss as a fraction of the dynamic pressure based on the film velocity. (Default = 1.0)
ISTIFF = 0	to bypass stiffness calculations (Default)
= 2	to calculate 16 stiffness and 16 damping coefficients
= 1	to calculate 16 stiffness coefficients
=-1	to calculate 4 radial stiffness coefficients
=-2	to calculate 4 radial stiffness and 4 radial damping coefficients
	Note that use of ISTIFF=1 or 2 with a symmetric model (ISYM=1) will also only calculate the radial coefficients.

IREADP A positive value will cause the program to read the pressures and velocity fields from a binary file (XXXX.999) generated by a previous run. The name of the file will be the same as the name of the output file specified in the variable 'OUTFIL'. (Default = 0). This file was generated from a previous run with the name XXXX.888 and must be renamed to XXXX.999 before running ICYL.

ISAVEP If this variable is non zero, the program will save the pressure and velocity fields in a file XXXX.888, where fname is the filename of the output file specified in the input file variable 'OUTFIL'. A negative value causes file to be rewound before saving. (Default = 8)

ISTOP = 0 To run current case. (Default)

= 1 to indicate that the previous input case was the last to be read. This is accomplished by the following line:

&INPUTS ISTOP=1/

Although the program will also stop when reaching the end of the file, the above line allows the user to store other namelist cases following it without the program attempting to run them.

Table 2 Variables that may be varied as parameters.

1	CREF =	.0000000	2	CD =	.6000000	3	DORIF =	.0000000
4	RADIUS=	.0000000	5	TS =	.0000000	6	TE =	360.0000
7	LENGTH=	.0000000	8	RHO =	.0000000	9	XMU =	.0000000
10	......=	.0000000	11	RPMJ =	.0000000	12	RPMB =	.0000000
13	ROUGHJ=	.0000000	14	ROUGHB=	.0000000	15	......=	.0000000
16	......=	.0000000	17	EX =	.0000000	18	EY =	.0000000
19	ALFA =	.0000000	20	BETA =	.0000000	21	EXD =	.0000000
22	EYD =	.0000000	23	ALFAD =	.0000000	24	BETAD =	.0000000
25	FXG =	-999.0000	26	FYG =	-999.0000	27	MXG =	-999.0000
28	MYG =	-999.0000	29	ECR(1)=	1.0000000E-10	30	ECR(2)=	1.0000000E-08
31	ECR(3)=	1.0000000E-06	32	TOL(1)=	.0000000	33	TOL(2)=	-1.0000000E-06
34	TOL(3)=	1.0000000E-04	35	PR1 =	.0000000	36	PL1 =	.0000000
37	PR2 =	.0000000	38	PL2 =	.0000000	39	PCAV =	.0000000
40	PSUP =	.0000000	41	XKE =	1.000000			

PARAMETRIC EVALUATION:

The five variables below allow the user to run a number of cases, by varying one of the variables in Table 2. This table also gives the default values of these parameters.

IPAR Number of the input variable in Table 2 that will be varied as a parameter. For example, use IPAR = 11 to vary RPMJ. See table at end of program output. (Default = 0)

PAR1 First value of parameter

PAR2 Last value of parameter

PARINC Increment for parameter. (Do not set this value if NPAR is specified) (Default = 0)

NPAR — Number of values the parameter will take (negative to use logarithmic scale). NPAR will be calculated from PAR1, PAR2 and PARINC if NPAR = 0 and PARINC>0. (Default = 0)

For example, the following line of input will cause the program to run 10 cases, changing the x-component of eccentricity ratio (EX) from 0.0 to 0.9 in increments of 0.1:

IPAR=17, PAR1=0.0, PAR2=0.9, PARINC=0.1,

while the following line will vary the rotor speed (RPMJ) from 1,000 to 100,000 over 6 intervals in a logarithmic scale:

IPAR=20, PAR1=1.E3, PAR2=1.E5, NPAR=-7,

DIAGNOSTICS CONTROLS:

KDIAG = 0 — No diagnostics are written. (Default)

= 5 — To write all the namelist &INPUTS to output file

= 8 — To output pressures every iteration

IRESET = 0	To use the pressure distribution from the previous case as the initial guess. (Default)
= 1	To reset the pressure distribution guess to zero. Use this when changing the size of the grid (M, N, ...) from the previous case or when the pressure distribution from the previous case is to be discarded.

4.0 OUTPUT DESCRIPTION

4.1 Text

The first part of the output file consists of an identical copy of the input file. This part is terminated by a long horizontal line. The second part of the output consists of the key input variables as interpreted by the program described in English with their corresponding units. Seal dimensionless quantities (Λ_b, Λ_j, Re^*, Re_o^*, and Λ_r, Λ_e) discussed in section **2.1** are also listed. This part is also terminated by a long horizontal line. The last part of the output consists of the results as follows:

The pressure distribution is first given in tabular form, with the axial coordinate direction increasing from left to right and the circumferential coordinate direction increasing from top to bottom.

This is followed by the rotor position (x and y components of eccentricity and misalignment ratios) as well as the forces and moments acting on the rotor. The rotor position should match exactly the values specified, unless the external forces and moments were specified. The forces and moments generated by the film pressure should match closely the negative of the externally applied values specified (Fxg, Fyg, etc) when the outer loop iterations have converged.

This is followed by the maximum film pressure and minimum film thickness, identified by the integer coordinates where they occur.

If NPOCK>0, this is followed by the orifice diameter as well as the pressures and volumetric flows through each pocket, as well as a sum of these flows.

The dynamic stiffness and damping coefficients, when requested, are printed as a matrix where the column corresponds to the displacement or rotation and the row corresponds to the force or moment. The units for any given stiffness or damping value will be the force unit given at the end of its row divided by the displacement unit given at the top of its column.

The last part of the results gives the volumetric flows at the boundaries of the seal model as well as the torque and power loss.

Note that all quantities (forces, flows, dynamic coefficients, etc.) refer to the full seal length, even if only half is modeled with a symmetric right-hand boundary (ISYM = 1).

Additional second and third parts of the output just described above are repeated for subsequent cases, also separated by long horizontal lines. Listings of output files generated by ICYL are given in Appendix A and discussed in Section 5 under sample problems.

4.2 Graphics

The user may examine graphically the film thickness or pressure distributions by running the three dimensional plotting program PLOT3D, by selecting "VIEW" "PLOTS..." from the menu bar.

This program is completely interactive and self-explanatory.

Support is provided for VGA monitors and HP LaserJet Series II printer in 150 DPI resolution. Plots may be printed by clicking on "File" "Print" from the menu bar.

Table 3 Summary of sample cases

Case	Mesh Size	ISYM	Variable Found*	Variable Specified	App.exec time**	Features
EX1	5x11	0	dorif,P_{pock}	P_{pock},E_x,dorif	4.6 min	1-pocket
EX2	5x11	0	ϵ_x,ϵ_y,α,β,P_{pock}	F_x,F_y,M_x,M_y,dorif	11.6 min	1-pocket
EX3	5x11	0	α,β,P_{pock}	M_x,M_y,dorif	6.2 min	Tapered pocket
F3	9x61	1	-	all	29 min	Raleigh-step
F4	7x61	0	-	all	7.8 min	Axial taper
F9	5x73	1	K,B	all (3 preloads)	1.6 hrs	3-lobe
I1	5x61	1	dorif	P_{pock}	7 min	4-pocket
I2	5x61	1	P_{pock},K	ϵ_x,dorif	1.8 hrs	4-pocket
I3	5x61	1	ϵ_x,ϵ_y,P_{pock}	F_x,F_y,dorif	1.9 hrs	4-pocket
I4	9x61	0	K,B,P_{pock}	ϵ_x,α,dorif	7.7 hrs	4-pocket
I5	11x61	0	dorif	P_{pock}	5.2 min	8-pocket
I6	11x61	0	P_{pock}	dorif,ϵ_x,α	3.1 hrs	8-pocket
015	5x31	0	K,B	all	1 hr 45 sec	Roughness

* K,B indicate whether stiffness, damping coefficients were requested.
** on an IBM PS/2 model 70 (386 20-Mhz) computer.

5.0 SAMPLE PROBLEMS

A number of sample problems have been prepared to demonstrate the behavior and various features of the computer program. They are intended primarily for illustration and do not necessarily represent recommended seal designs. Table 3 summarizes the mesh size, approximate execution times (on a 20Mz 386 PC) as well as a list of what variables where specified and iterated for in the outer loop for the sample problems.

The complete input file is included at the top of the output file for each case. The filename used in this samples all used the prefix icyl. For example, EX1 used *fname* = icylEX1. Listings of sample output files are given in Appendix A.

Sample EX1, EX2 and EX3 were selected with a coarse (5x11) mesh covering a 90° sector in order to demonstrate the use of pressurized pockets and iterations for rotor position within a reasonable execution time. A pocket with a supply pressure of 100 psi was centered on the seal sector modeled.

Sample **EX1** contained two cases. In the first case, the pocket pressure was specified as 50 psi, resulting in an orifice diameter of 0.0137 inches calculated by the program. Both components of the resulting fluid film force are equal and the moments are zero, as would be expected at the concentric position. In the second case, the rotor was moved with to eccentricity ratio of $\epsilon_x = 0.1$ and given a misalignment ratio of $\beta = 0.1$ about the y-axis. With the value of orifice diameter already assigned from the first case, the pocket pressure and forces rise slightly, generating non-zero moments.

In sample **EX2**, external forces and moments equal to the negative of those resulting in EX1 were specified, in order to have the program iterate for the rotor radial and angular positions. Five unknowns, the four displacement components (ϵ_x, ϵ_y, α, and β) as well as the pocket pressure, are iterated for simultaneously. Although it wasn't needed, IREADP=1 was specified in order to illustrate the use of reading the pressure distribution from a previous run. The file 'ICYLEX1.888' was copied to ICYLEX2.999 for this run. Since the iteration was begun at the concentric position where the orifice was sized, the pocket flow error was zero and *increased* when the rotor was moved in the first iteration, causing the run to abort. When the limit on diverging iterations (MAXDIT) was increased to 2, the iterations converged in only 3 iterations to within a small error of the values expected ($\epsilon_x = 0.1$, $\beta = 0.1$).

In sample **EX3**, an axial taper of ±30% of the clearance from end to end was superimposed. This calculation might be desirable to see the effect of machining tolerances or imperfection on seal components. This was accomplished by decreasing the clearance by 0.0003 inches (DELTA(1,1)=-0.003) as well as using DELTA(2,1)=0.006. In this sample, the program was asked to find the angular rotor position such that no external moments where required, while the rotor eccentricity was varied, using ϵ_x = 0.1, 0.3 and 0.5 for the 1st, 2nd and 3rd cases, respectively. The results show that as the eccentricity is increased in the x-direction, the rotor twists about the y-axis in order for the moments generated by the film to be zero, resulting in β =0.050 and 0.17 at ϵ_x = 0.1 and 0.3, respectively. The case of ϵ_x=0.5 resulted in a negative film thickness with the appropriate error message and recommended user action:

- REDUCE THE SPECIFIED APPLIED FORCES/MOMENTS
- REDUCE THE SPECIFIED ECCENTRICITY/MISALIGNMENT

The resulting film thickness distribution is shown in Figure 10 and the pressure are shown in Figure 11.

Sample **F3** shows a 120° sector with a Raleigh step of linearly varying depth. The resulting film thickness distribution is shown in Figure 12 and the pressure are shown in Figure 13.

Sample **F4** shows a 120° sector with an axial taper in the right half (4<i<7) of 0.001 inches. Since two less intervals were used in the axial direction than in the previous cases, and since half as many iterations were required for the pressure distributions, the execution time was reduced from about 29 to 8 minutes. The resulting film thickness distribution is shown in Figure 14 and the pressure are shown in Figure 15.

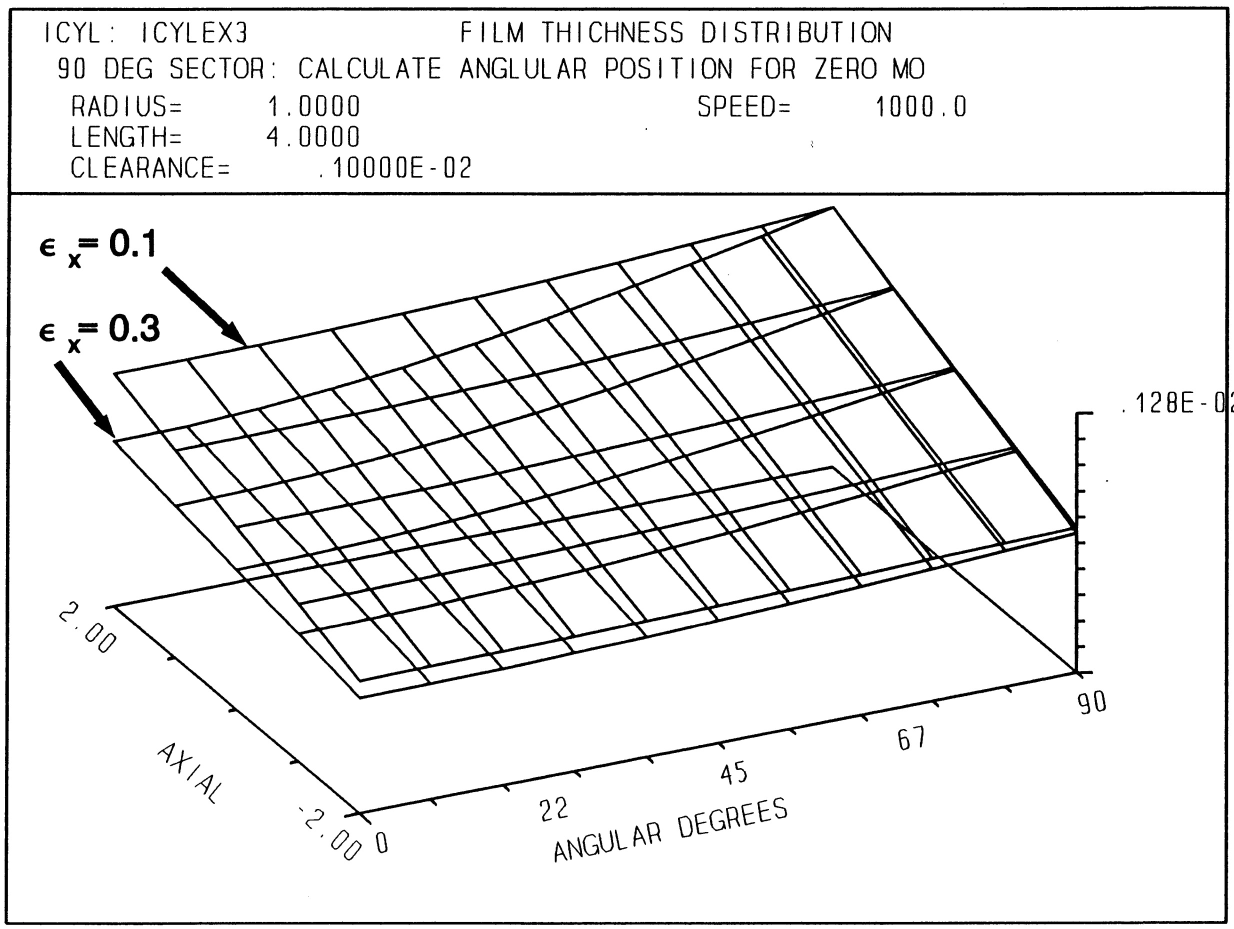

Figure 10 Film thickness distribution for sample **EX3**

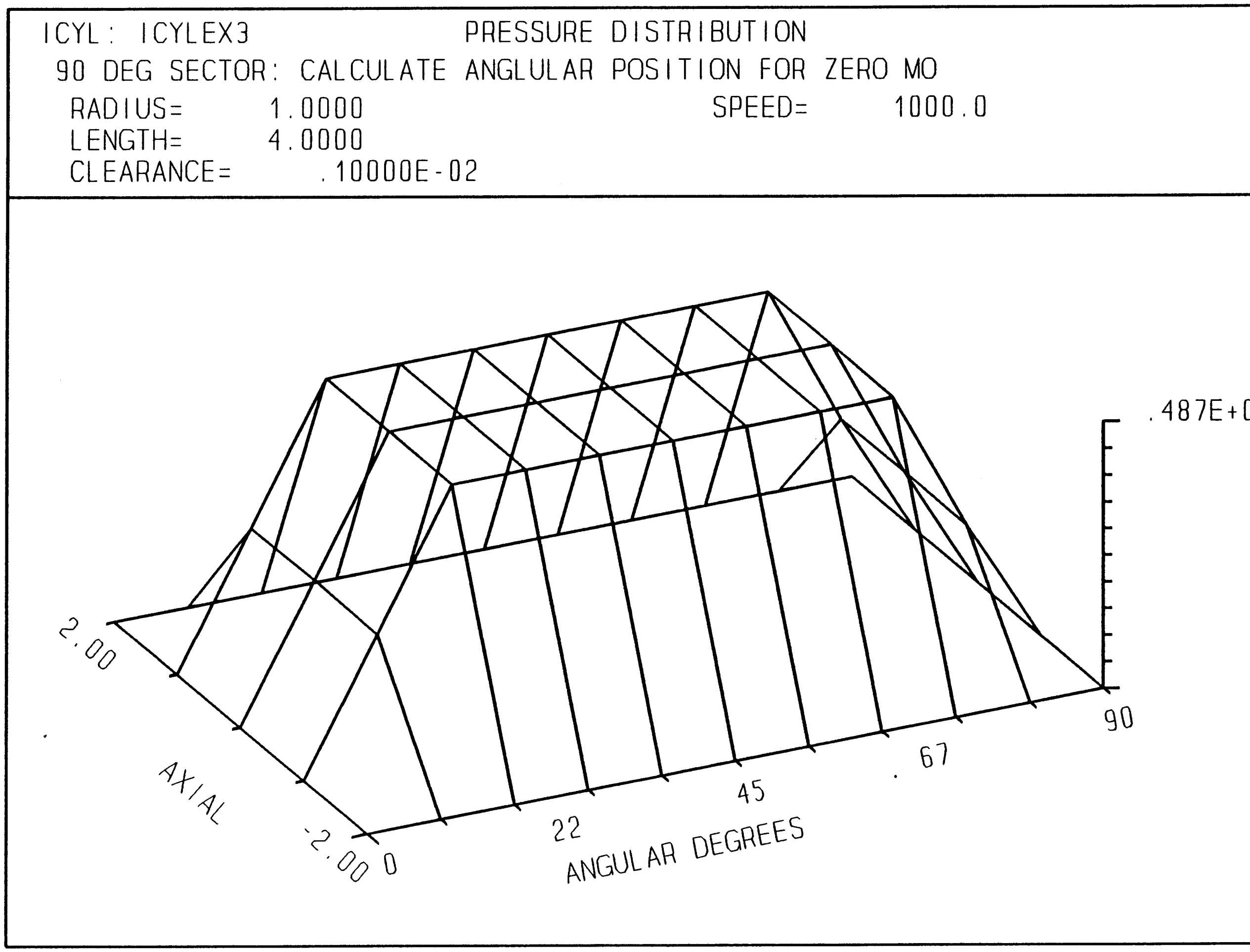

Figure 11 Pressure distribution for sample **EX3**

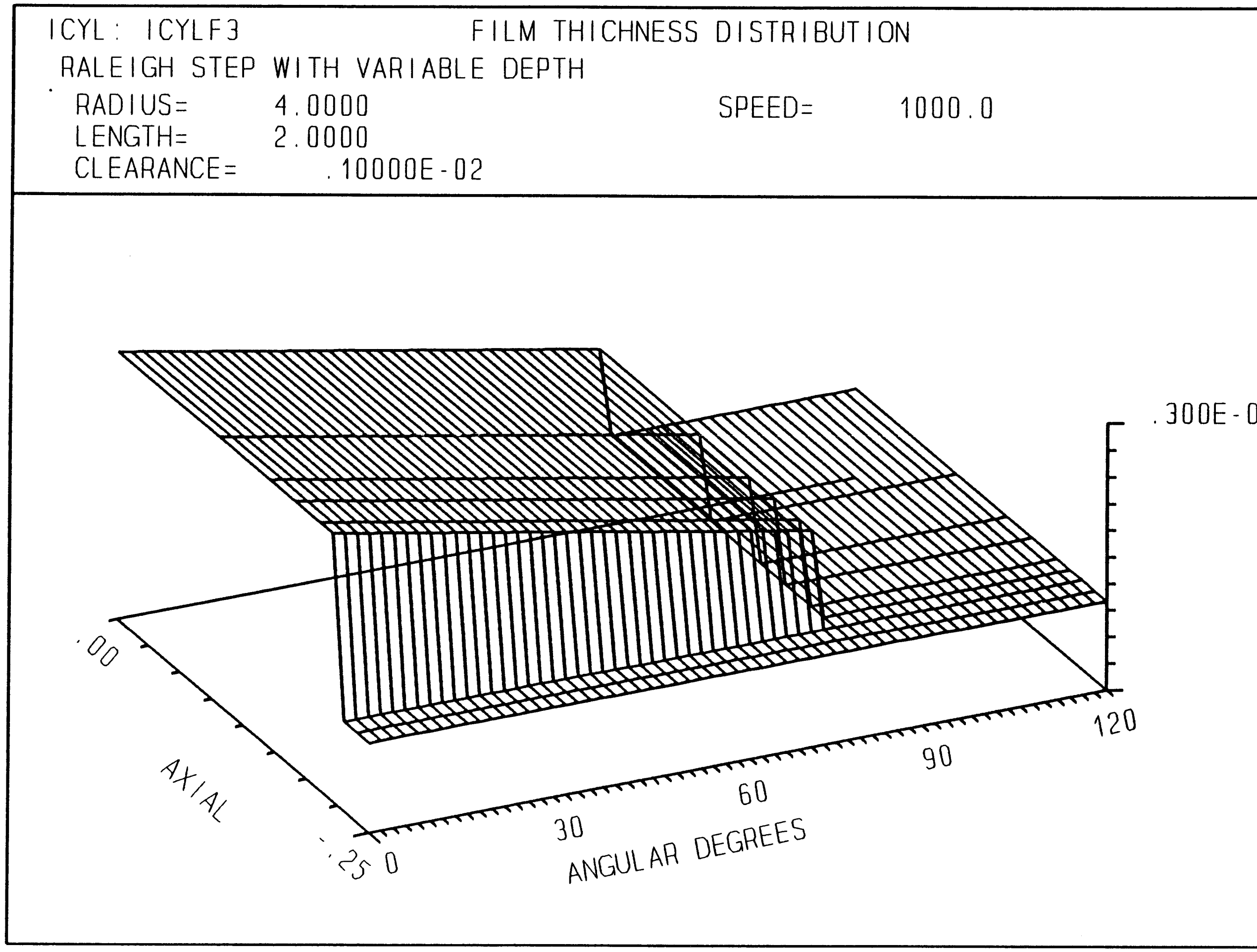

Figure 12 Film thickness distribution for sample **F3**

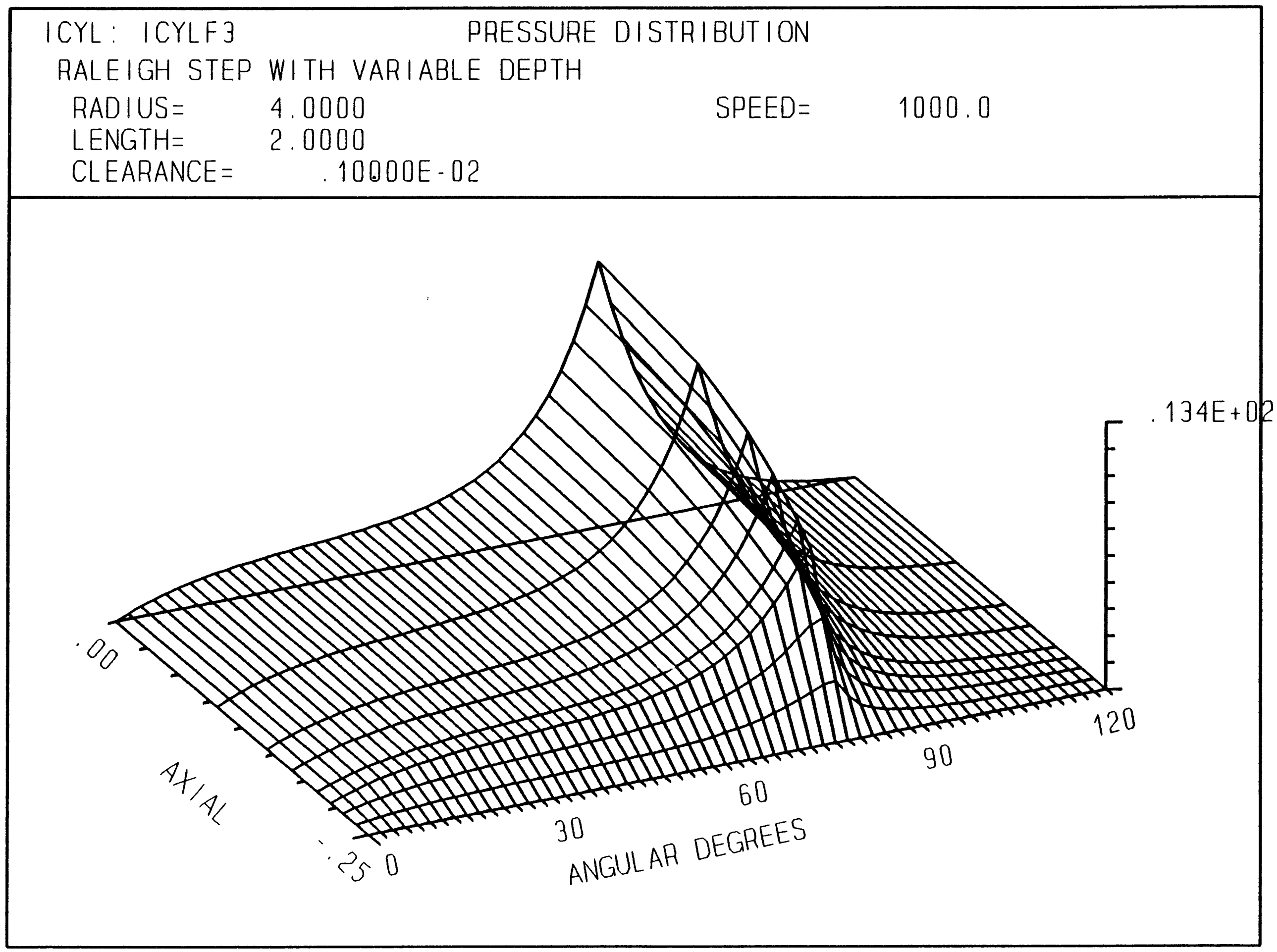

Figure 13 Pressure distribution for sample **F3**

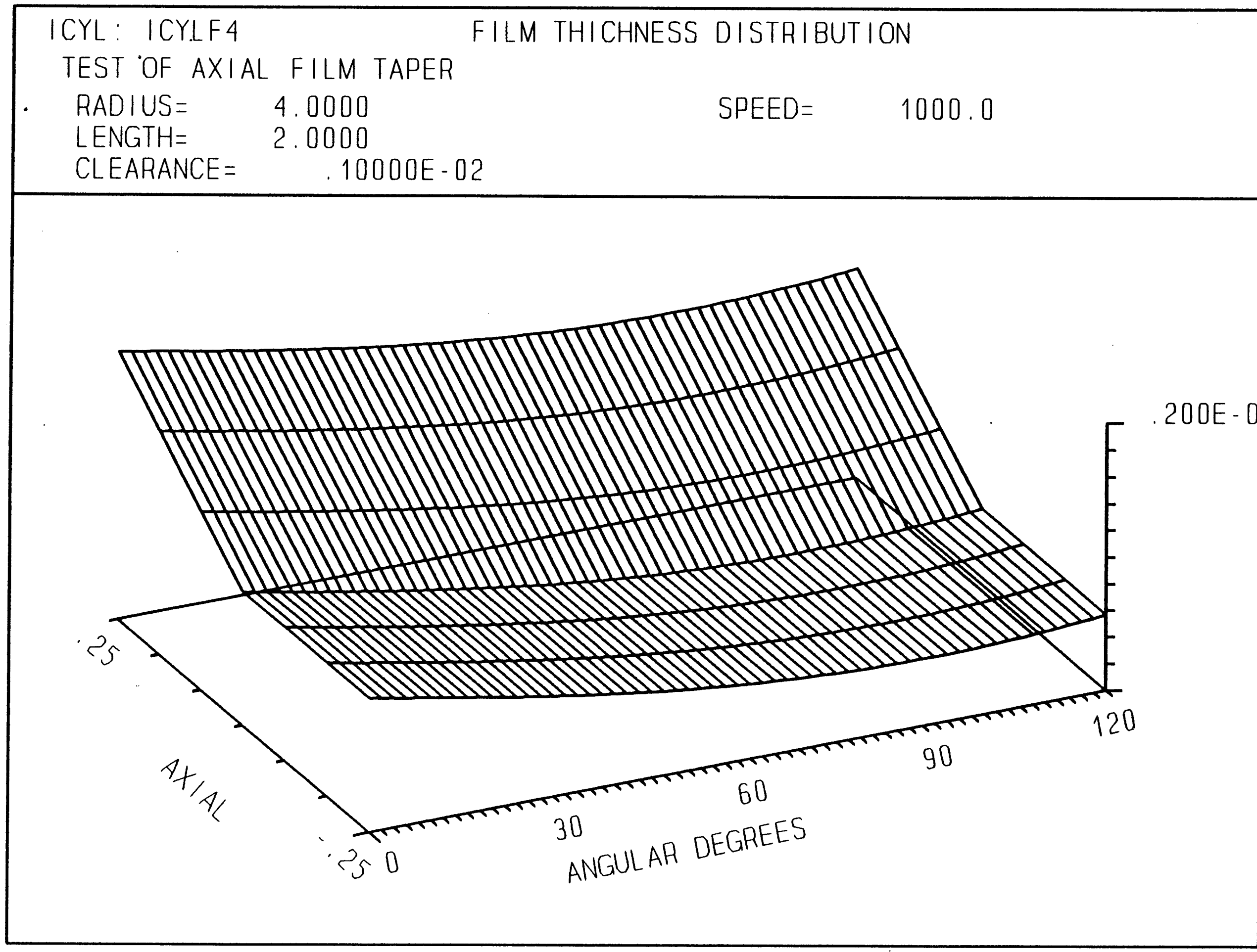

Figure 14 Film thickness distribution for sample **F4**

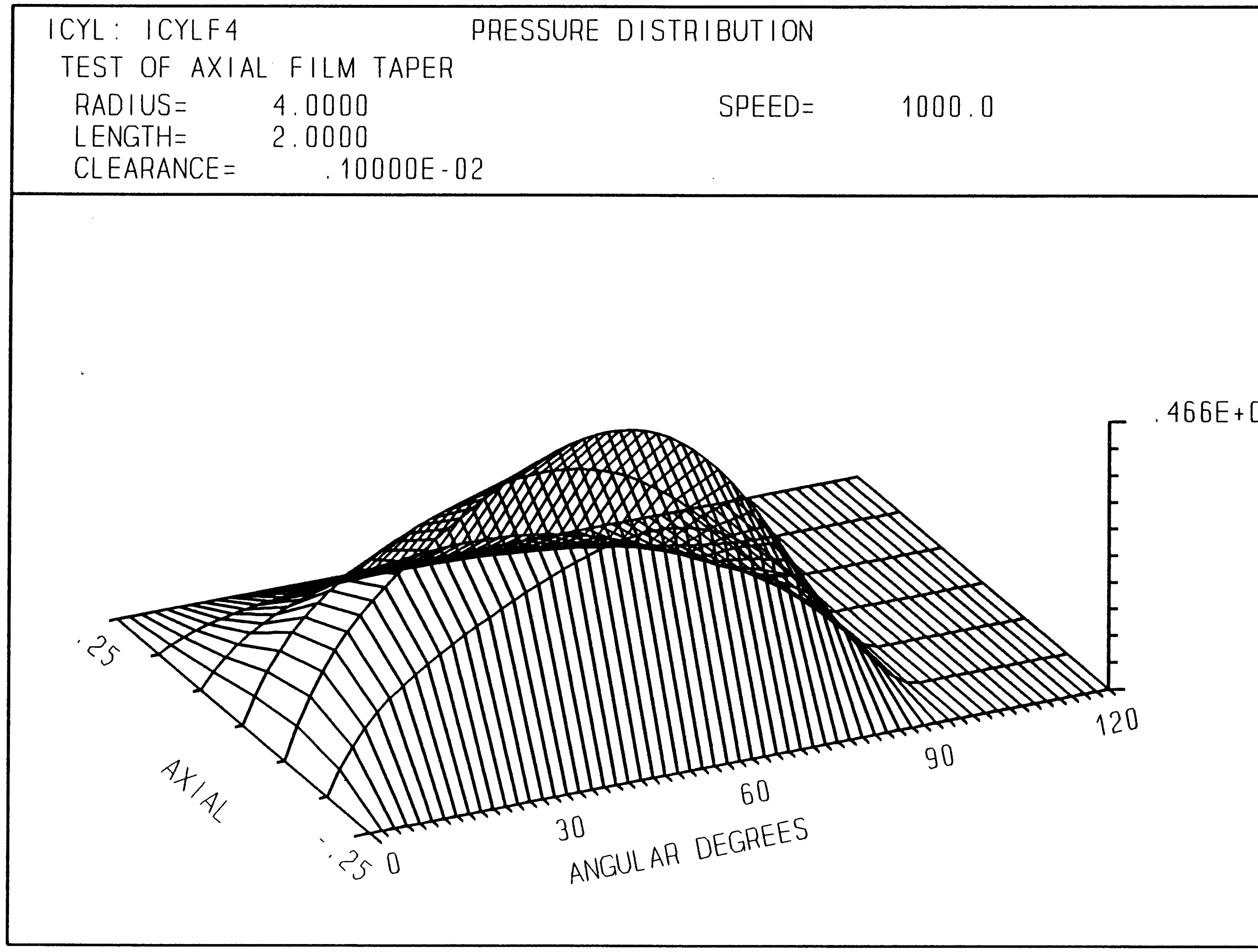

Figure 15 Pressure distribution for sample F4

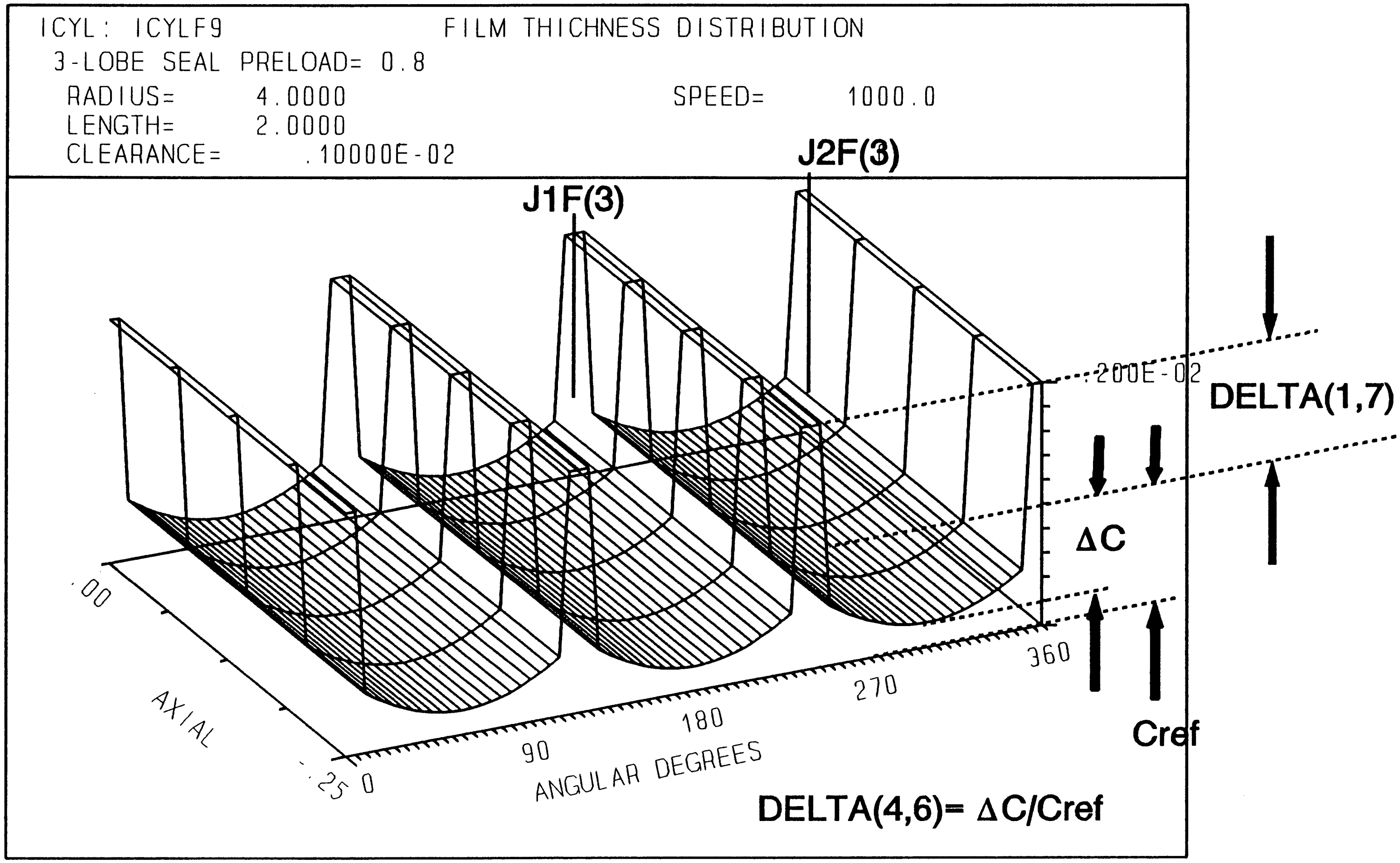

Figure 16 Film thickness distribution for sample **F9**

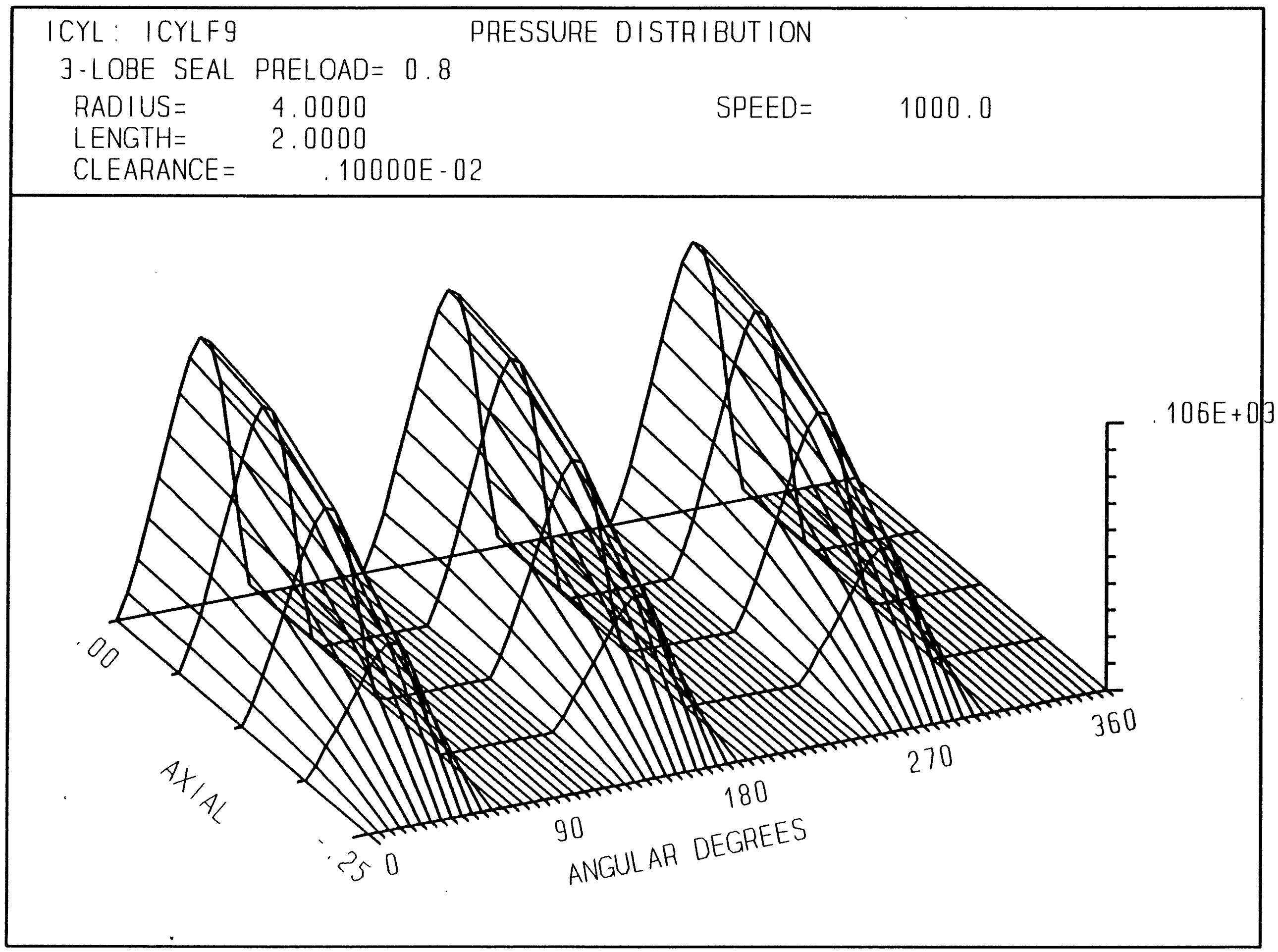

Figure 17 Pressure distribution for sample **F9**

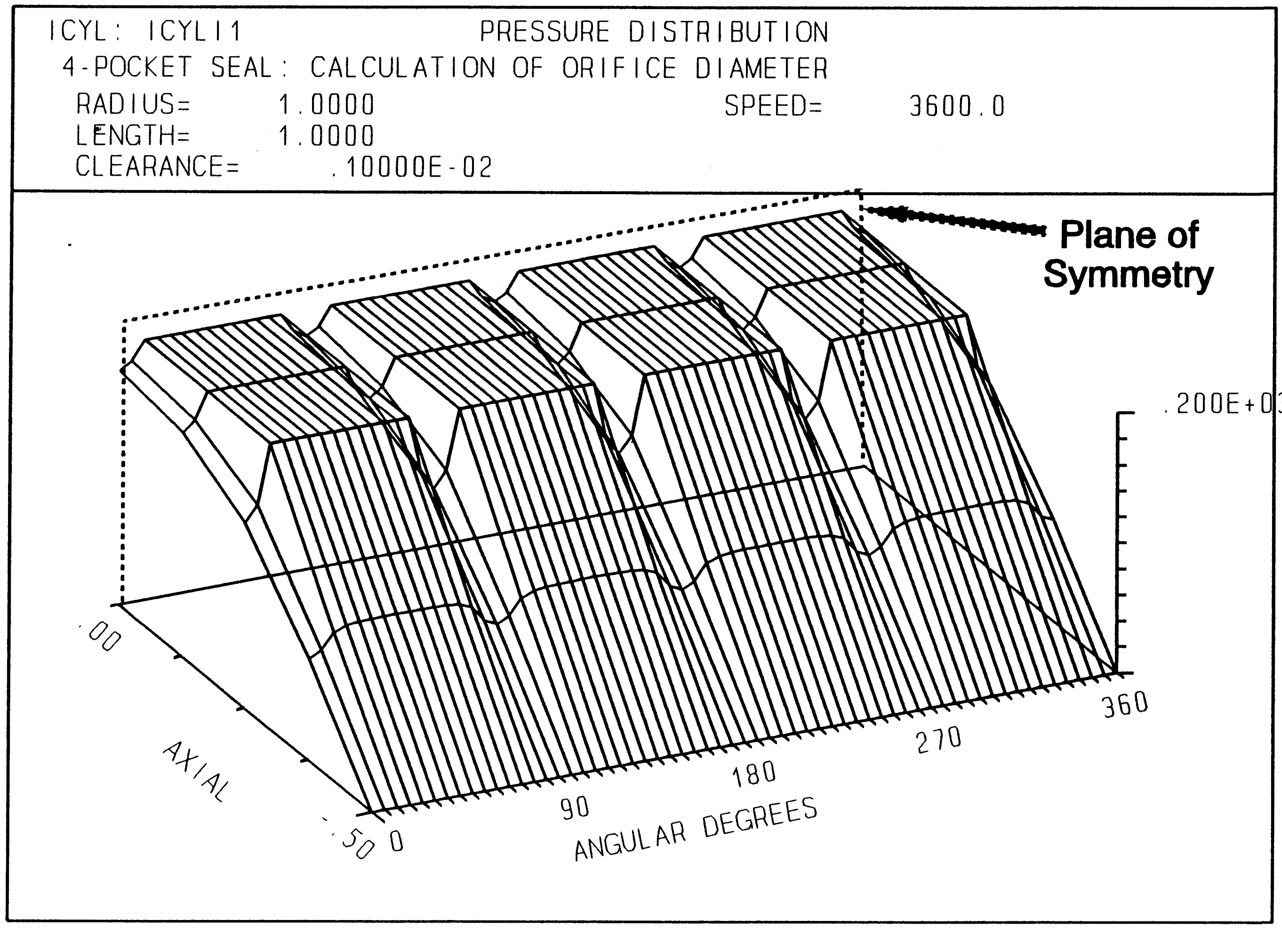

Figure 18 Pressure distribution for sample I1

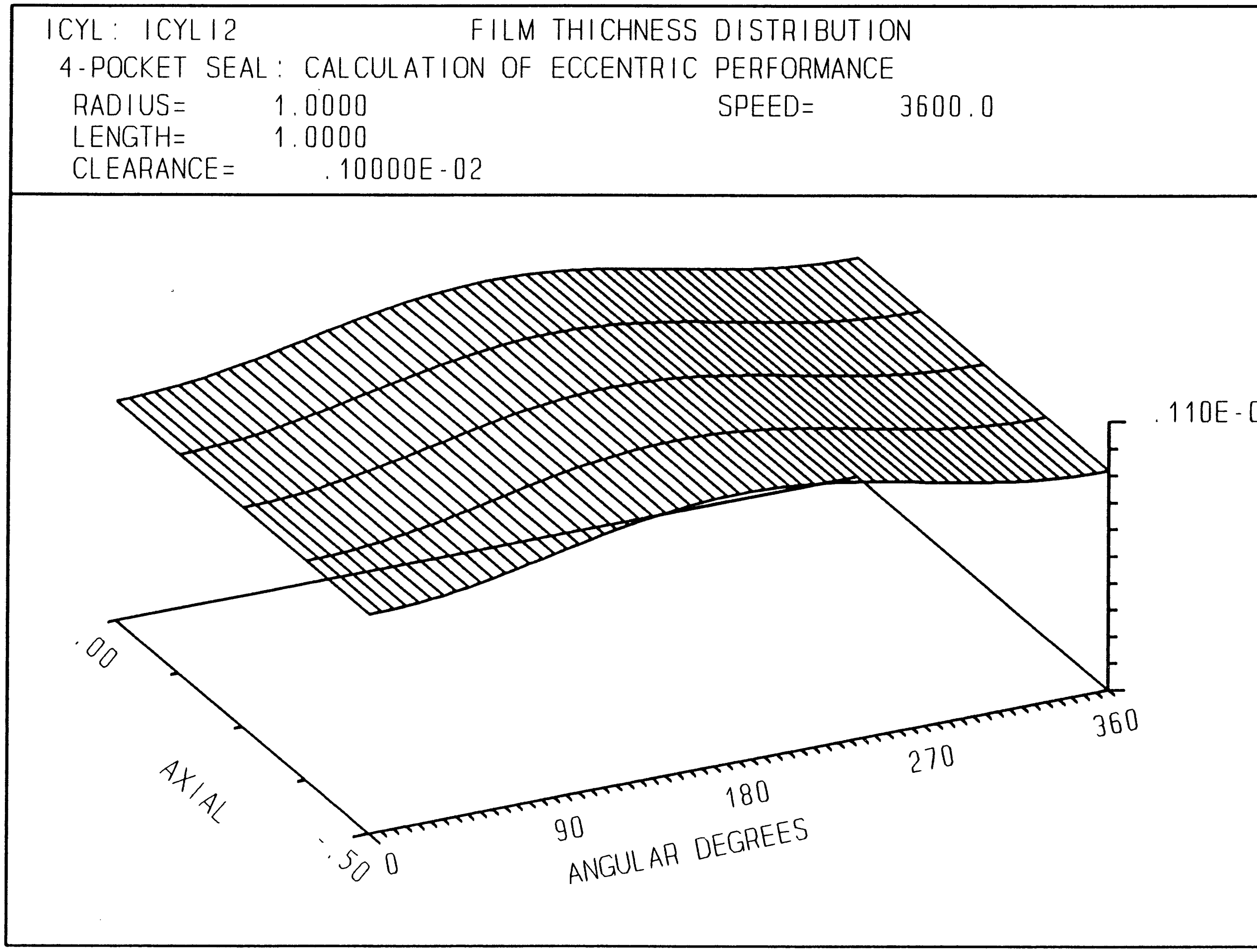

Figure 19 Film thickness distribution for sample I2

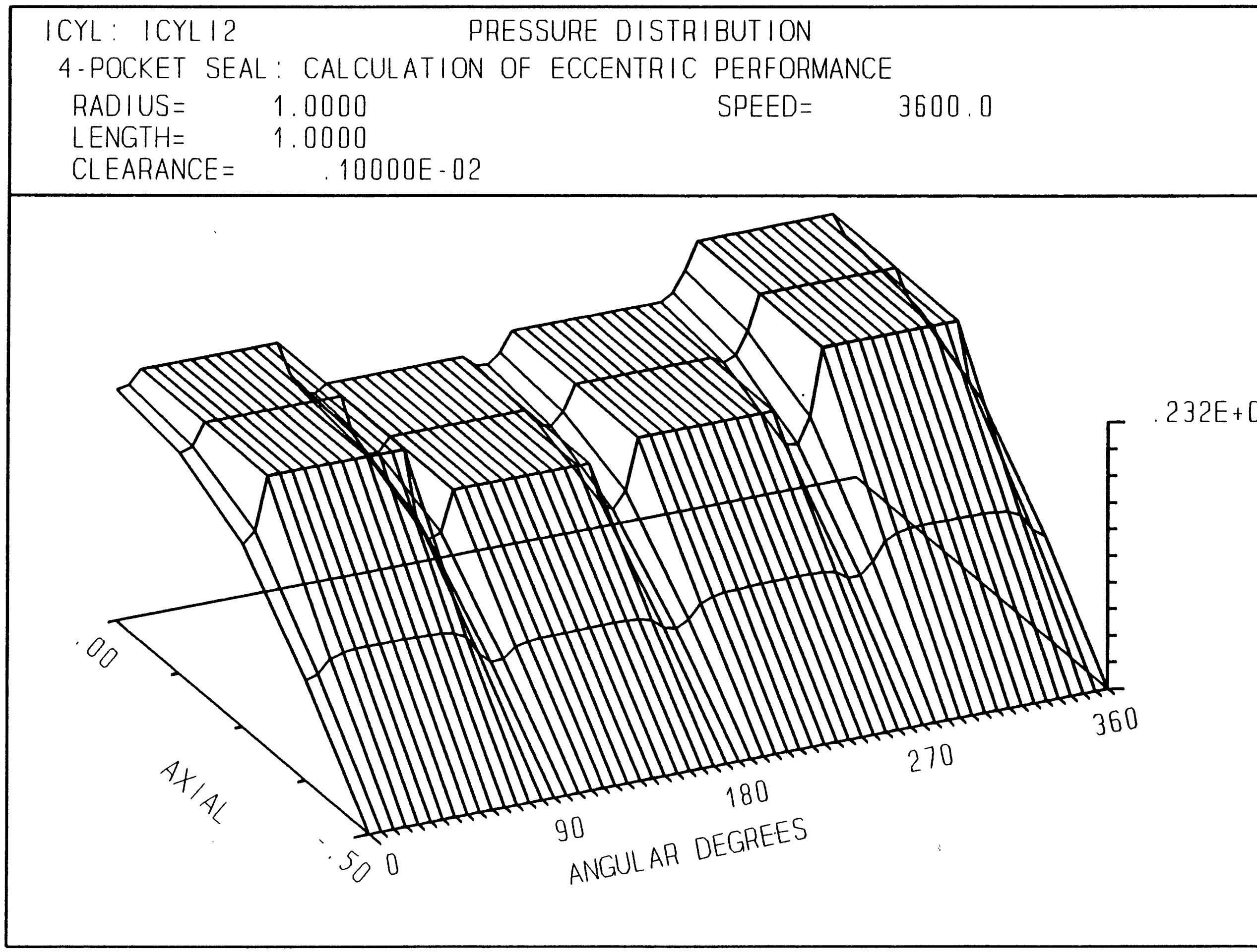

Figure 20 Pressure distribution for sample **I2**

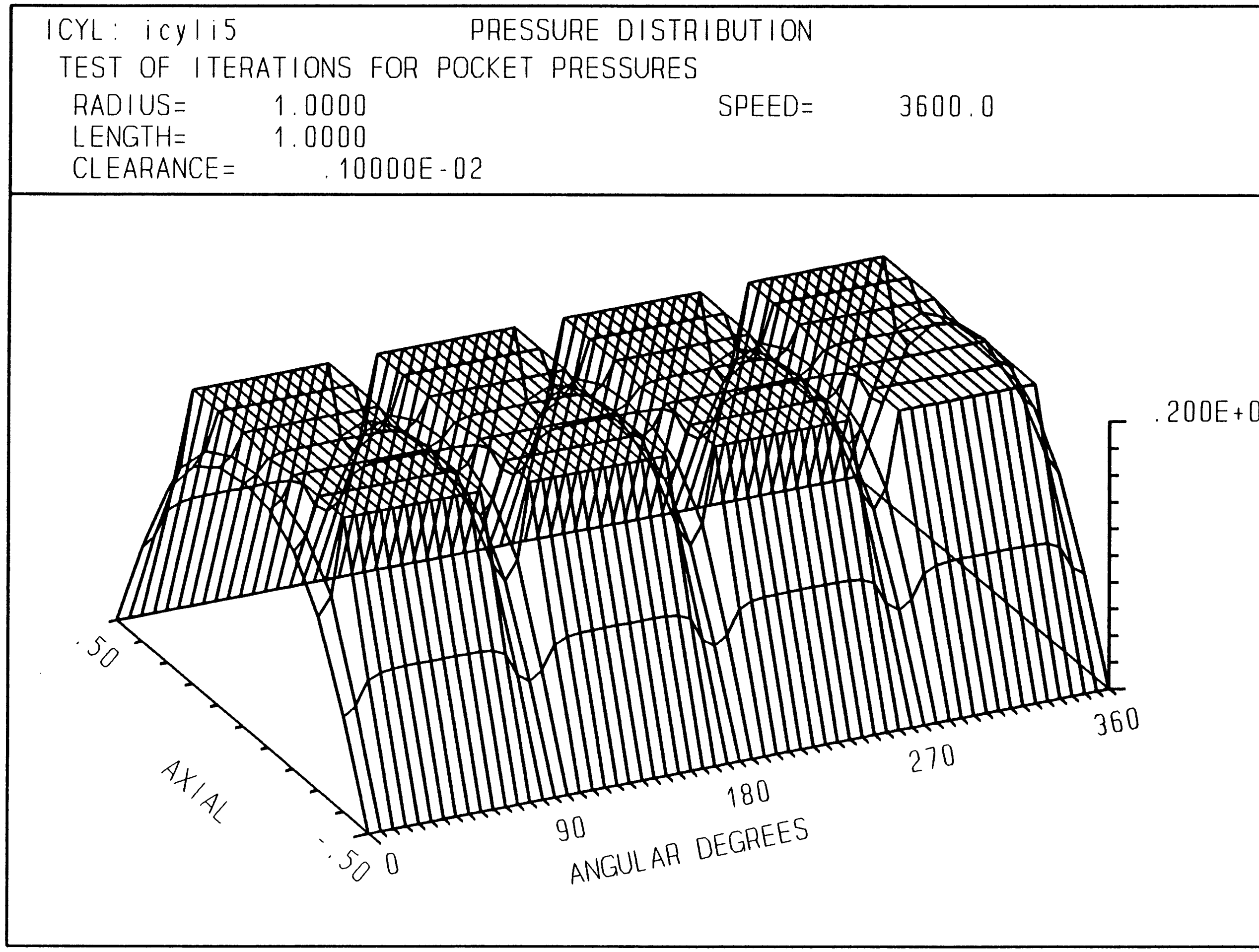

Figure 21 Pressure distribution for sample I5

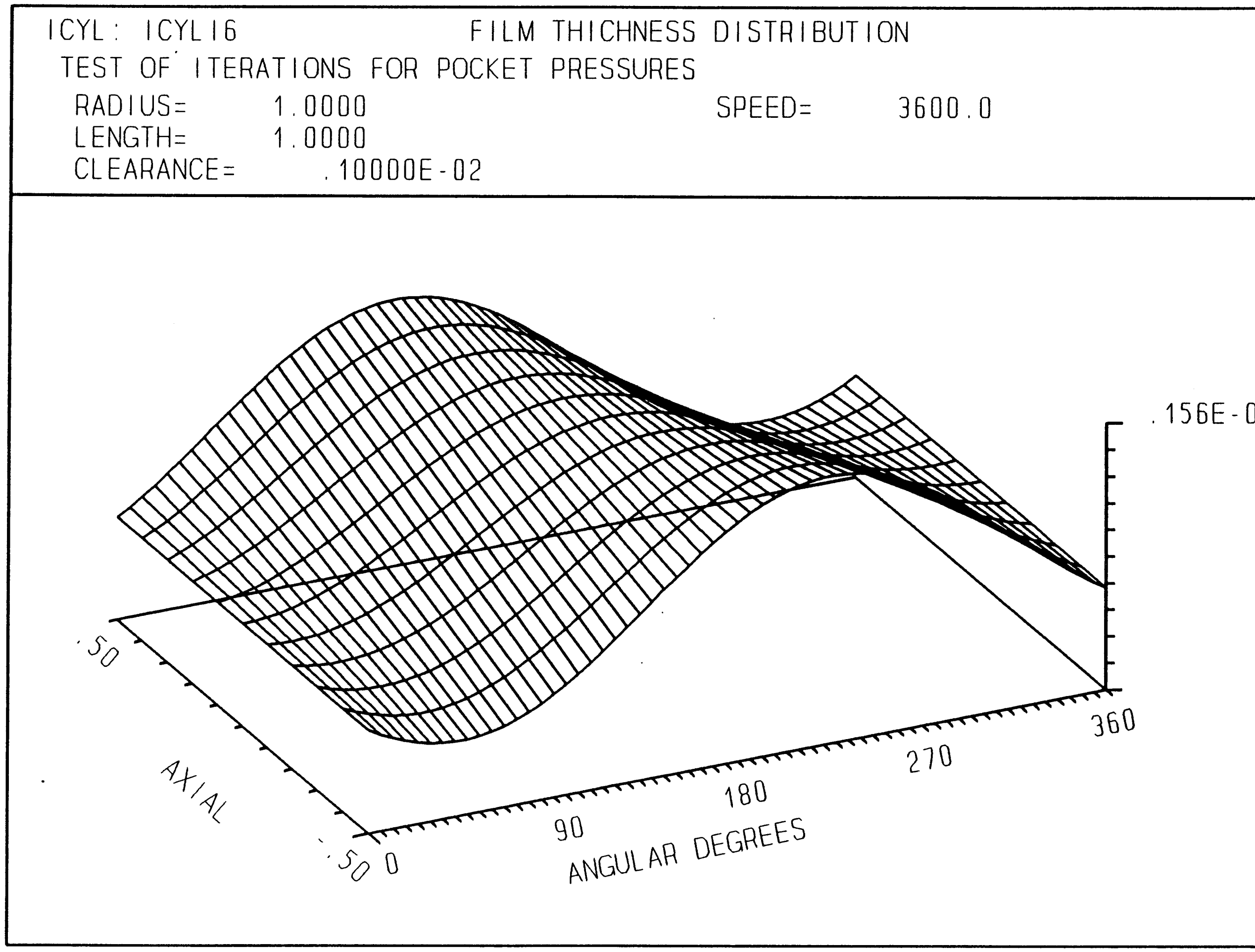

Figure 22 Film thickness distribution for sample **I6**

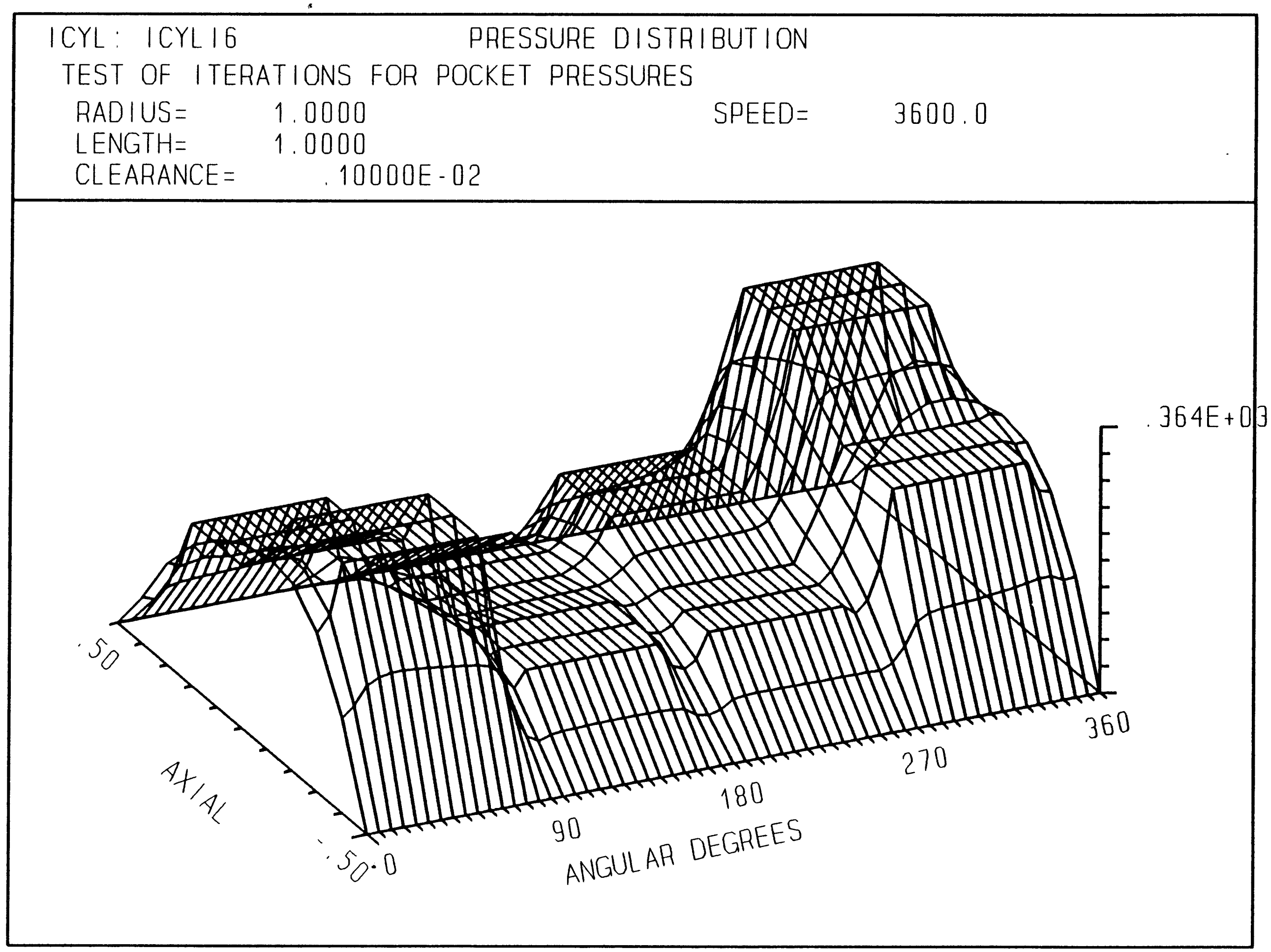

Figure 23 Pressure distribution for sample **I6**

Sample **F9** is that of a full 360° seal with three 60° lobes. The dynamic coefficients was requested as the preload was increased from 0.1 to 0.3 in the middle case, to 0.8 at the last case. The resulting film thickness distribution is shown in Figure 16 and the pressure are shown in Figure 17.

Samples I1 through I4 are more realistic models since they represent the full circumference. In sample **I1**, the program takes about 7 minutes to calculate the orifice diameter for given pocket pressures. The resulting pressure distributions is shown in Figures Figure 18. Sample **I2** is the same as I1 except that the eccentricity and orifice diameter were prescribed, requiring the program to solve for the four pocket pressures. Also, in I2, IREADP was specified to read a previous pressure file. The file ICYLI1.888 was copied to ICYLI2.999 for this run. The resulting film thickness and pressure distributions are shown in Figure 19 and Figure 20, respectively. In sample **I3**, the orifice diameter as well as the radial force were prescribed, requiring the program to solve for the radial position as well as the pocket pressures.

Sample **I4** shows the dramatic increase in execution time with the number of axial grid lines, M. Sample I1 is a model of only half of the seal (ISYM=1) at the concentric position with the pocket pressures specified. This run executes in less than 7 minutes in spite of the 5x61 mesh. Samples I4 is a model of the full axial length (ISYM=0), with an 11x61 mesh, in which non-zero ϵ_x, α and orifice size are specified and all 32 dynamic coefficients are requested. This run took 7.7 hours to execute. Calculations for each of these coefficients require convergence of the outer iteration loop with four unknown pocket pressures.

Sample **I5** and **I6** are models representing the full circumference and length with two rows of 4 pockets. The orifice size is calculated in the concentric aligned position in I5 while I6 calculates what happens when the rotor is displaced to the $\epsilon_x = 0.4$ position and rotated about the x-axis by $\alpha = 0.4$. For I5, the resulting pressure distribution is shown in Figure 21. For I6, the film thickness and pressure distributions are shown in Figure 22 and Figure 23, respectively.

Sample **O15** is a case of a plain cylindrical seal with increasing housing wall roughness. The wall roughness (ROUGHB) was varied from 1×10^{-6} to 1×10^{-3} inches in a logarithmic scale using IPAR=14 and NPAR=-4. This input was used to generate the top curve of critical mass versus roughness shown in Figure 24. The stabilizing effect of housing roughness is more pronounced at the higher pressures due to the increased effect of inlet inertia. The last lines in the input file show how one would run additional values of pressure within the same run. These were not run because they were placed after the line with ISTOP=1 in order to reduce the size of the output file.

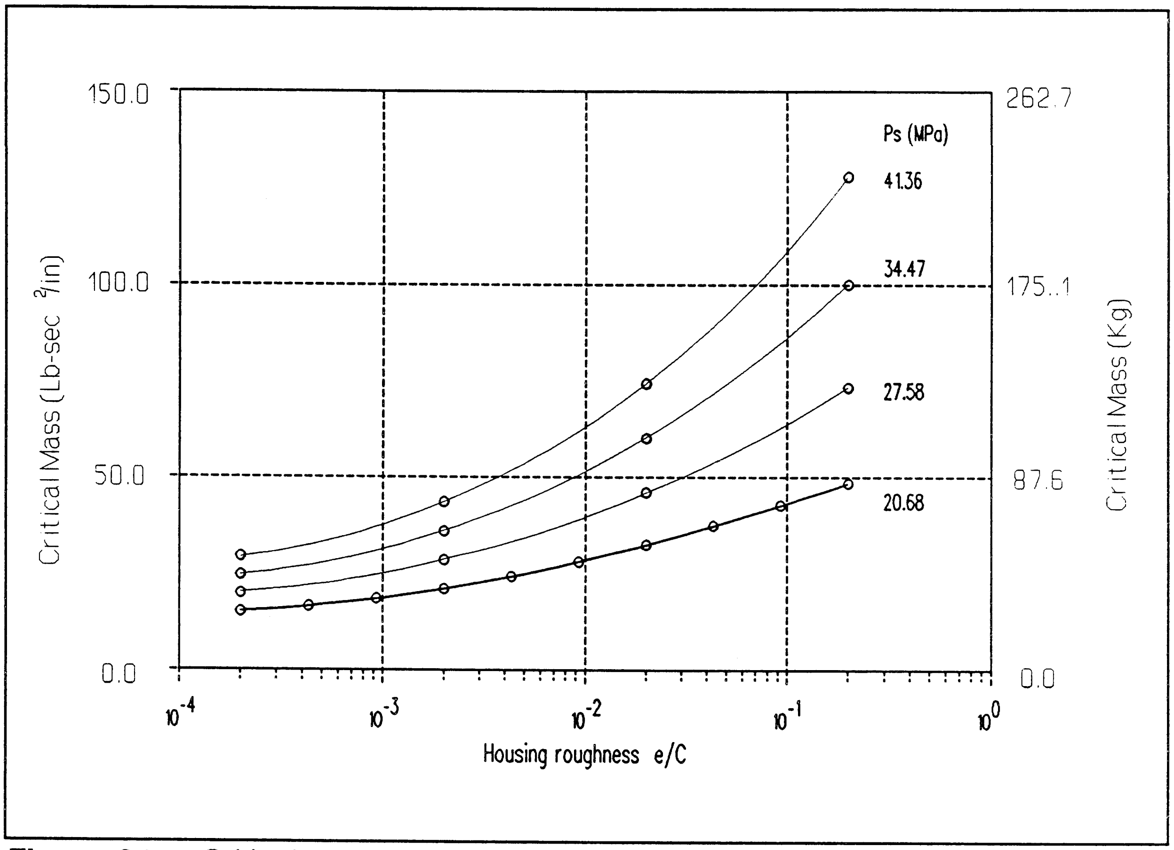

Figure 24 Critical mass versus housing roughness

6.0 VERIFICATION

ICYL has been compared with the results of two other MTI computer codes as well as currently published data. The first comparison was against a generic bearing program with many similar capabilities (GBEAR) based on the turbulent lubrication theory of Ng and Pan. A second comparison against a laminar bearing program (GASBEAR) was used to verify the calculations of moments and angular coefficients. Finally, comparison were made against calculations published by San Andrés in Reference [16].

6.1 Comparison against MTI other codes

The first of the MTI computer codes is GBEAR which is fully described in Reference 1. This program is based on the turbulent lubrication theory of Ng and

Pan[13], and does not include surface roughness, housing rotation or calculation of misalignment coefficients. It includes inertia pressure drop at exit from pockets but not from the seal ends.

Calculations were made with a 90° seal sector at an eccentricity ratio of 0.5 and with a pocket at its center with a prescribed pressure ratio of 0.5. Table 4 shows a comparison of pocket flow, orifices size, force, and stiffness and damping coefficients. As expected, comparisons of GBEAR against ICYL with the same friction model (IFRIC=0) yielded nearly identical results. With the new friction model that includes surface roughness effects, ICYL calculates lower torque(-32%), lower pocket flow (-13%) and orifice size (-7%), and force components(-6%). Very good agreement in the stiffness coefficients (-4%), and slightly higher damping coefficients(+13%) are obtained.

Other comparisons against GBEAR in the laminar regime and without pockets yielded identical results.

A second MTI computer code with the fluid compressibility turned off (GASBEAR) was used to verify the calculation of the 24 stiffness and damping coefficients which involve rotor misalignment. GASBEAR was written for use in conjunction with plane journal bearings and cylindrical seals and does not treat turbulence or pressurized pockets. The comparison, in the laminar regime and with the same finite difference mesh, yielded identical coefficients.

6.2 Comparison against published data

A detailed comparison was made of the 5-pad hydrostatic bearing discussed by San Andrés in Reference [16]. This high speed hybrid journal bearing operates at relatively high levels of pressurization and relatively low viscosity lubricants, in which the effects of pressure-induced turbulence become important. Fluid inertia may also be important. Figure 25 is a plot of the pressure distribution at the

Table 4 Comparison against GBEAR.

	GBEAR	ICYL IFRIC=0	ICYL IFRIC=3	ICYL IFRIC=4
Recess flow (in^3/s)	25.75	25.21	20.931	22.316
Orifice diam. (in)	0.0833	0.0820	0.0752	0.0776
Torque (lb-in)	14.38	14.32	8.791	9.771
Power (Lb-in/s)	45,171	44,971	27,617	30,696
Fx (Lb)	3,694	3,358	3,352	3,477
Fy (Lb)	-3,488	-3,122	-3,083	-3,346
Kxx (10^6 Lb/in)	2.352	2.267	2.329	2.344
Kxy (10^6 Lb/in)	-1.461	-1.378	-1.280	-1.397
Kyx (10^6 Lb/in)	-1.998	-1.874	-1.871	-1.961
Kyy (10^6 Lb/in)	1.573	1.481	1.406	1.564
Bxx (Lb/in)	232.08	234.79	269.01	274.46
Bxy (Lb/in)	-175.53	-175.87	-194.38	-199.65
Byx (Lb/in)	-174.78	-174.10	-192.40	-200.56
Byy (Lb/in)	173.87	173.79	187.57	196.53

concentric position, while Figure 26 and Figure 27 plot it for 40% eccentricity ratio of the journal between pockets and over a pocket center, respectively. Reproductions of the corresponding pressure distributions published by San Andres are included in the figures for comparison. It is noticed that the size of the pressure drops at the pocket exits (i.e., entrance to the film) as well as the general pressure distribution are comparable for both analyses.

At the concentric position, bearing flow requirements calculated by ICYL is 42 versus about 44 l/min reported by San Andres. Figure 28 and Figure 29 are plots comparing the direct and cross coupled stiffness coefficients while, Figure 30 and Figure 31 compare the direct and cross coupled damping coefficients, respectively, versus eccentricity ratio. In general, ICYL predicts about 35% higher direct stiffness, 10% lower cross coupled stiffness coefficients, and 15% lower direct

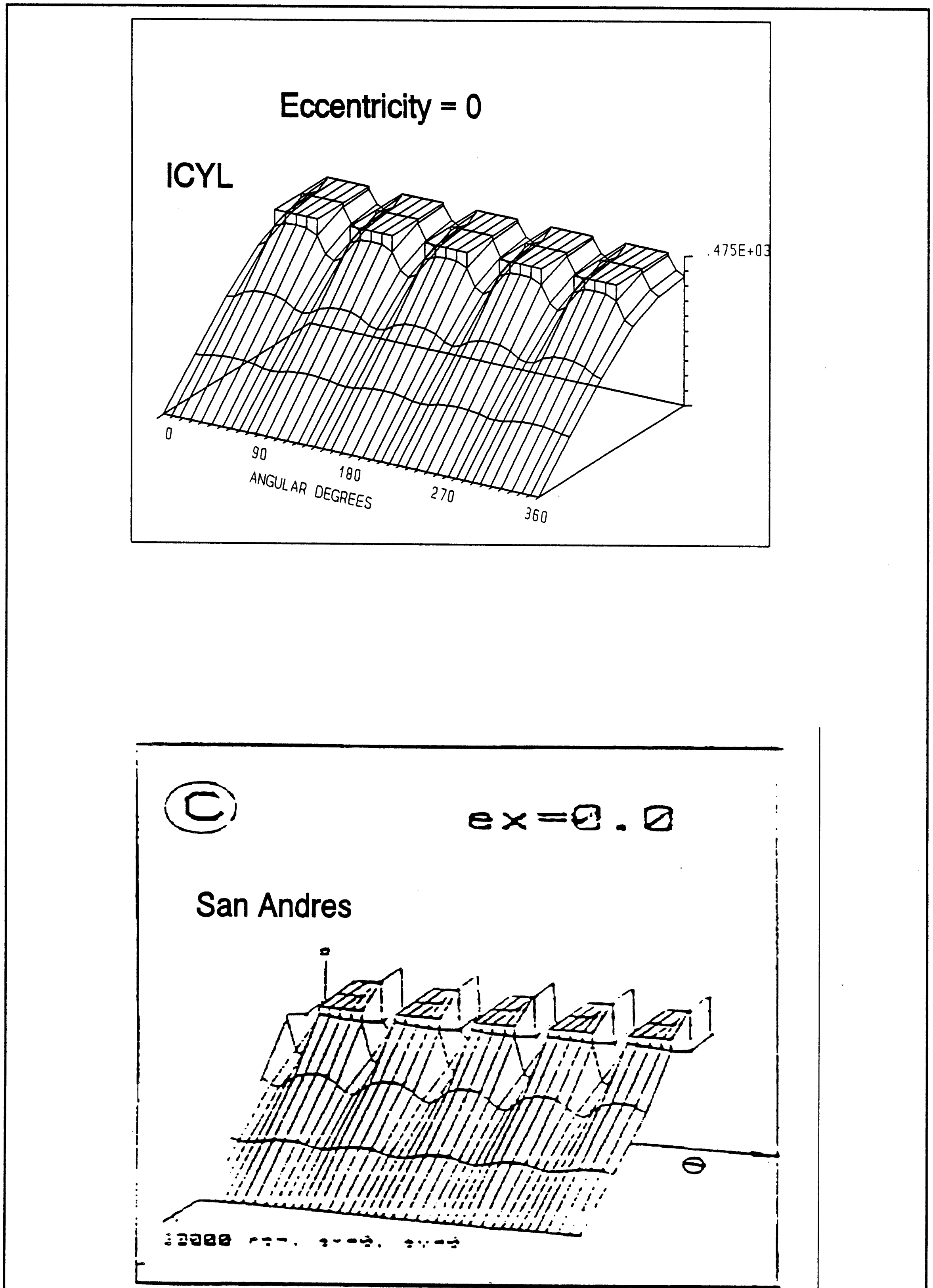

Figure 25 Comparison to SanAndres' 5-pad bearing at concentric position

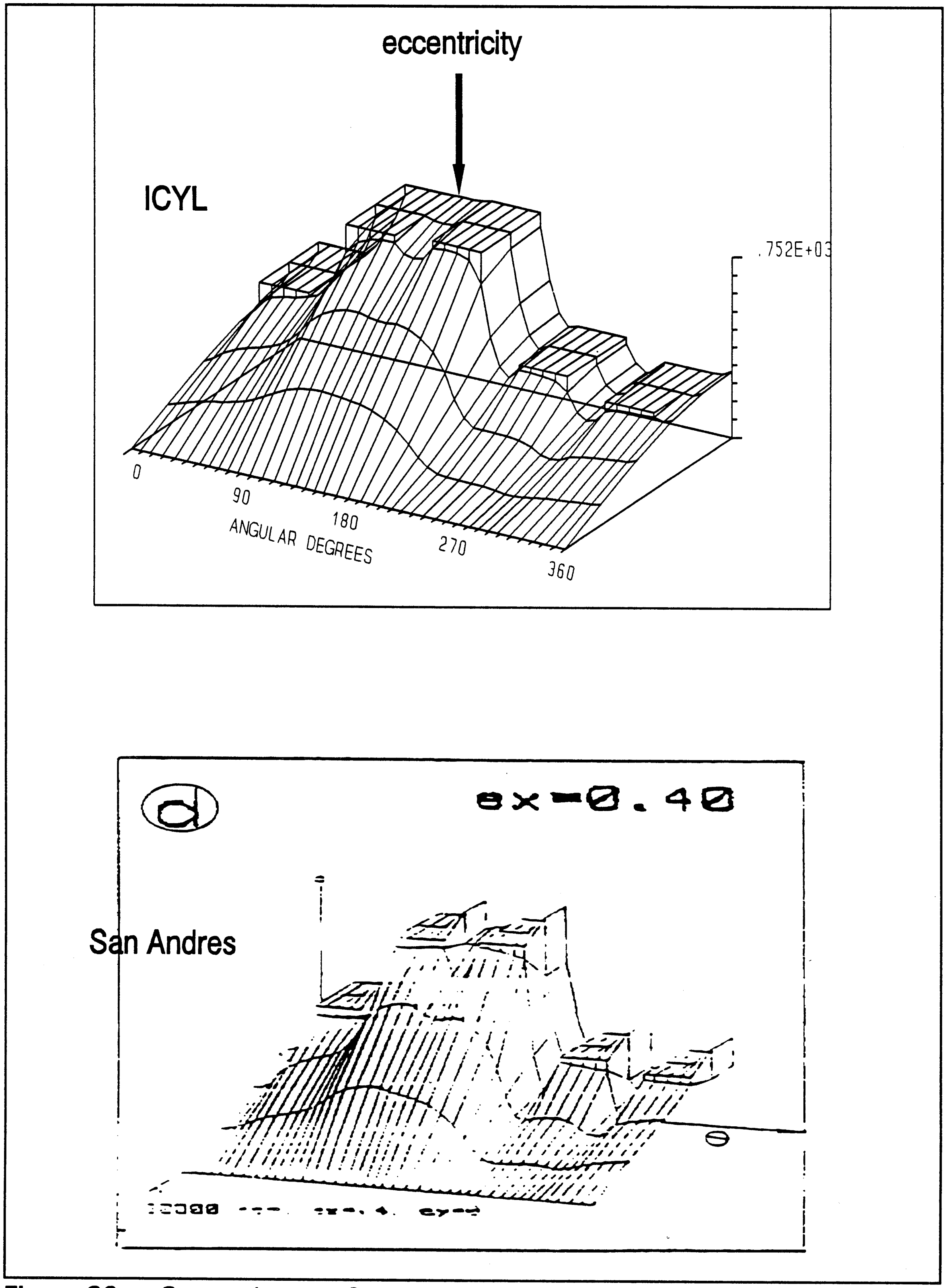

Figure 26 Comparison to SanAndres' 5-pad bearing with 40% eccentricity between pockets

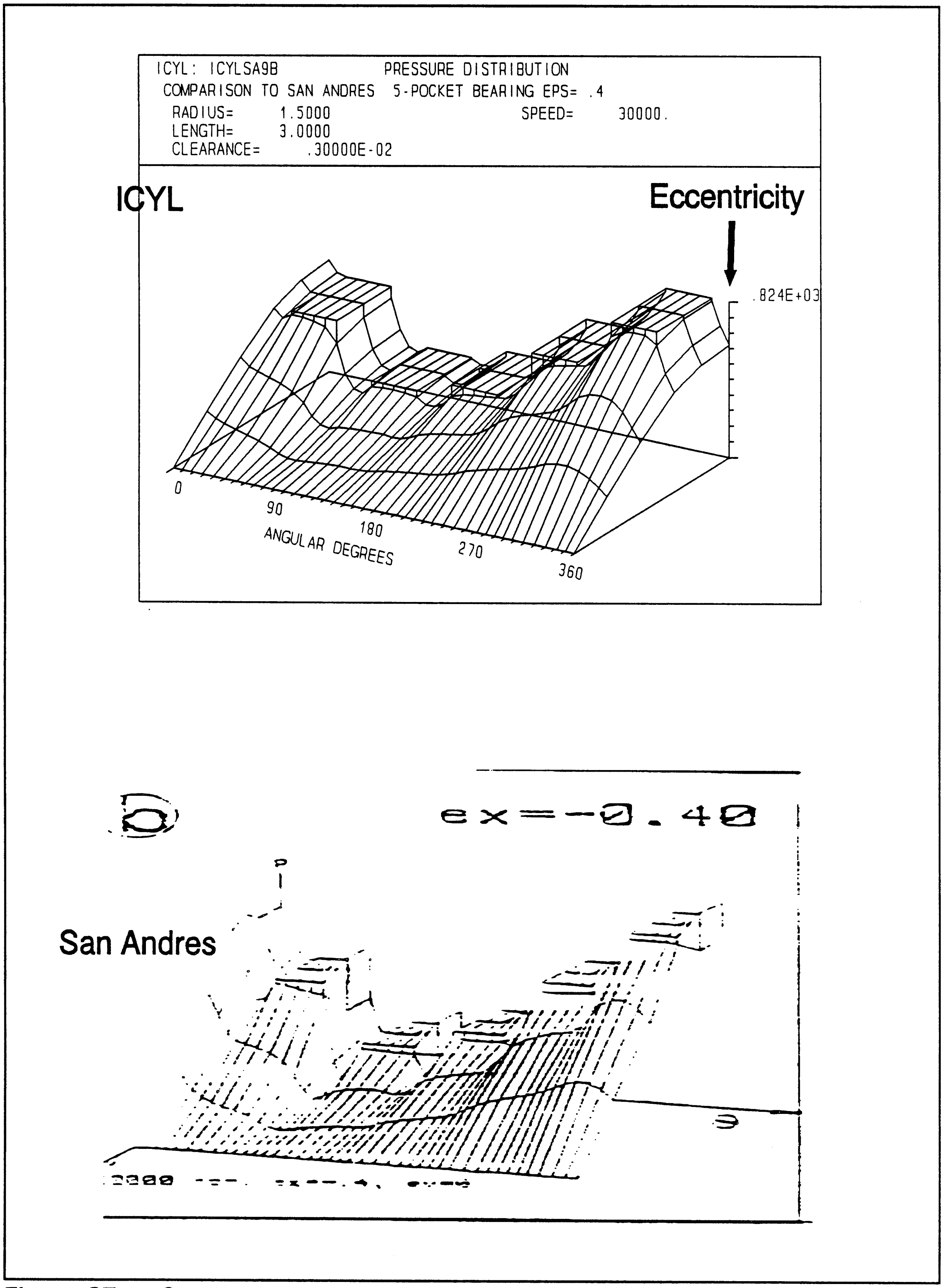

Figure 27 Comparison to SanAndres' 5-pad bearing with 40% eccentricity over pocket

damping at the concentric position. With increasing eccentricity ratio, the coefficients are observed to behave similarly and some of the discrepancies decrease. The cross-coupled damping coefficients with ICYL are equal in magnitude, opposite in sign and zero at the concentric position, as is expected with an incompressible fluid. San Andres' non-zero concentric value (60 kN-s/m) is due to the fluid compressibility in the pocket. Figure 32 shows the critical mass versus eccentricity. The concentric value of 119 Kg shows better stability than predicted by San Andrés, which predicts an unstable bearing with a 30 Kg mass.

The analysis of San Andrés includes the effect of fluid inertia in the film as well as some special effects inside the pocket, such as fluid compressibility and a one-dimensional circumferential pressure rise downstream of the orifice. There is also a slight difference in friction law used: MTI's analysis follows the formula derived by Nelson[12] for Moody diagram, in which the term containing the Reynolds number is raised to the 1/3 power while San Andres uses the same formula with the power changed to 1/2.65 for a more restricted range of Reynolds numbers.

The above comparisons should provide reasonable verification, as the only discrepancies between the results can be explained by the different friction models and features between the codes.

Listing of the inputs used in these comparisons are given in Appendix B.

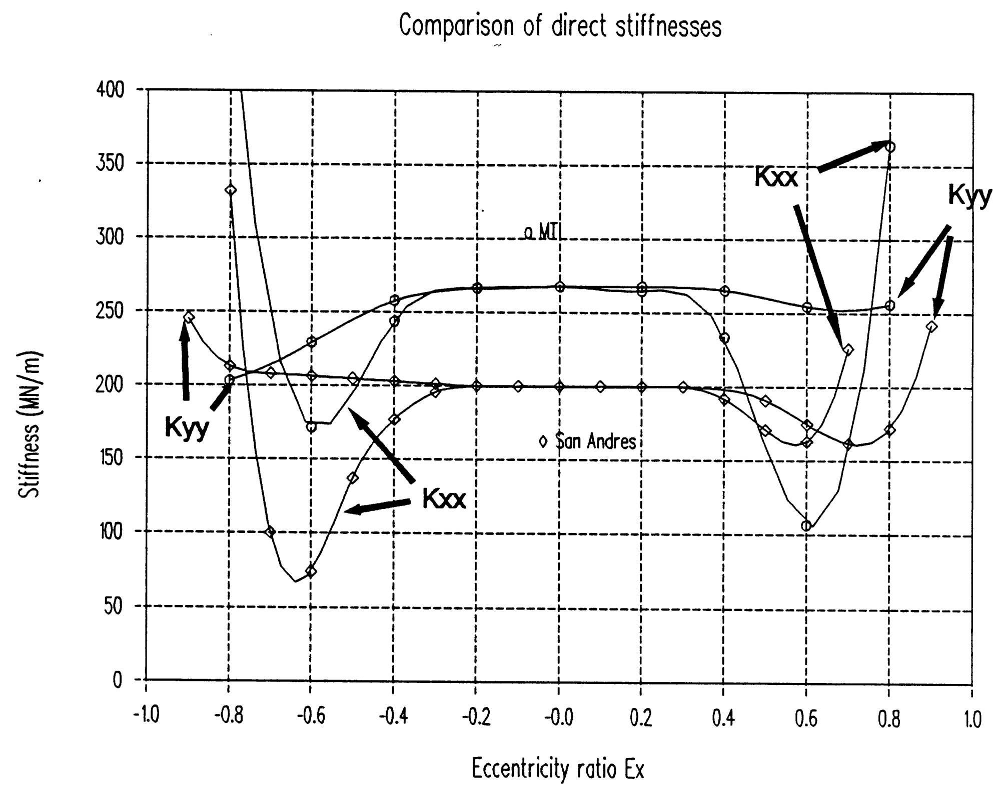

Figure 28 Comparison of direct stiffness coefficient

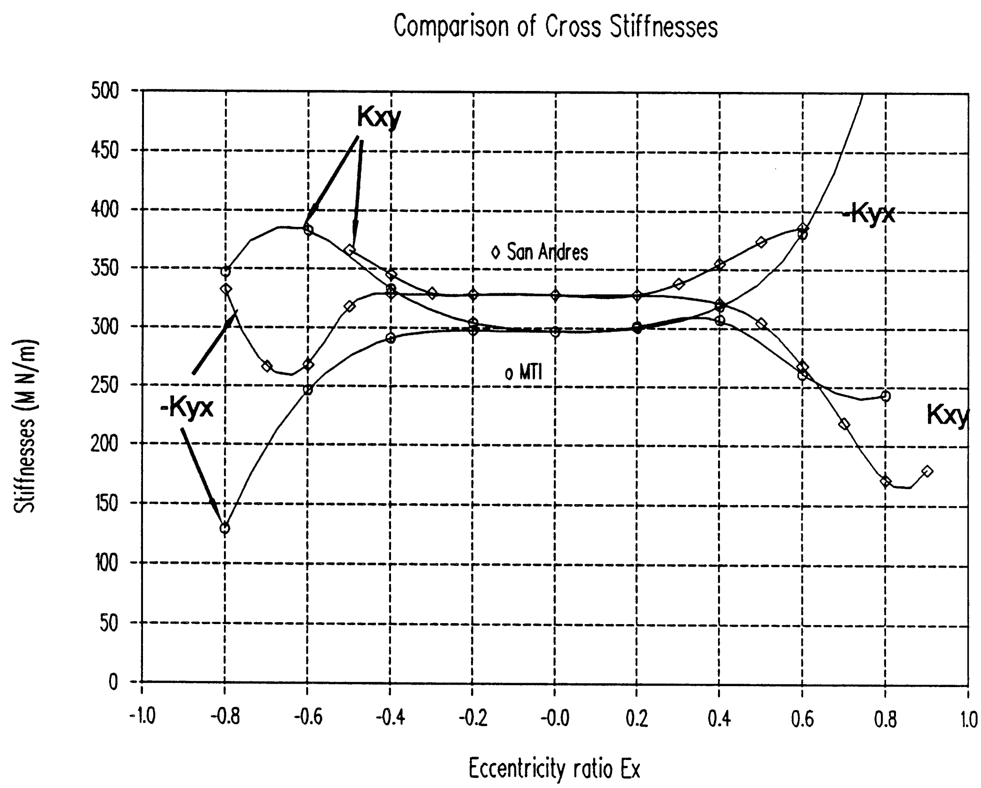

Figure 29 Comparison of cross stiffness coefficients

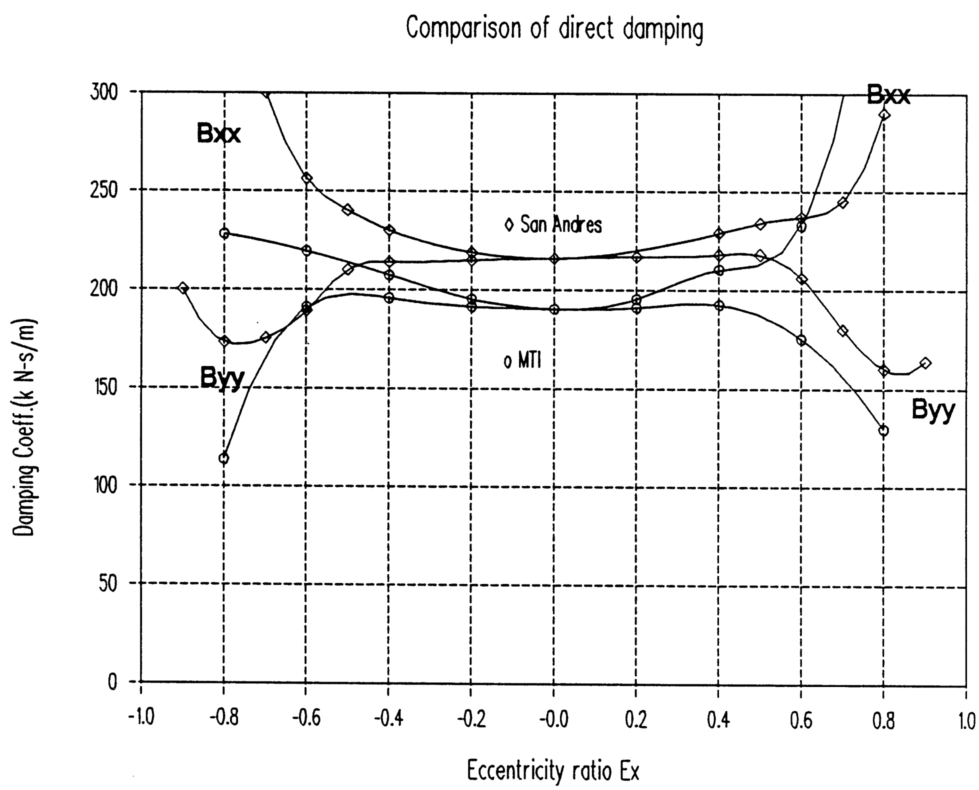

Figure 30 Comparison of direct damping coefficients

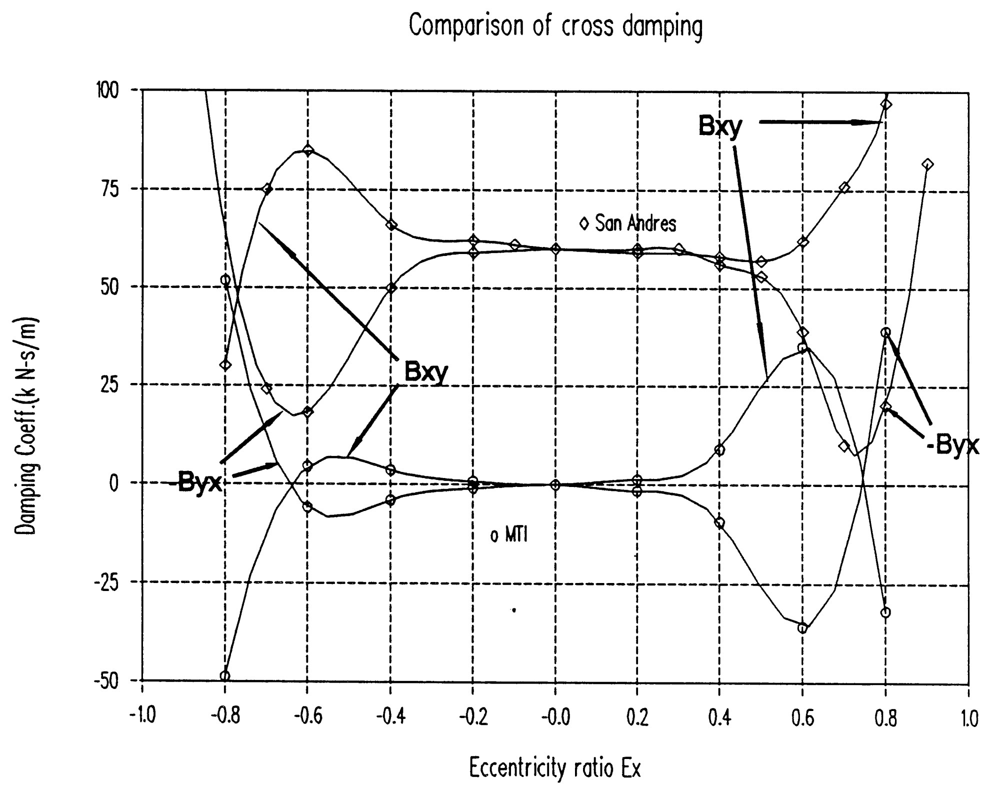

Figure 31 Comparison of cross damping coefficients

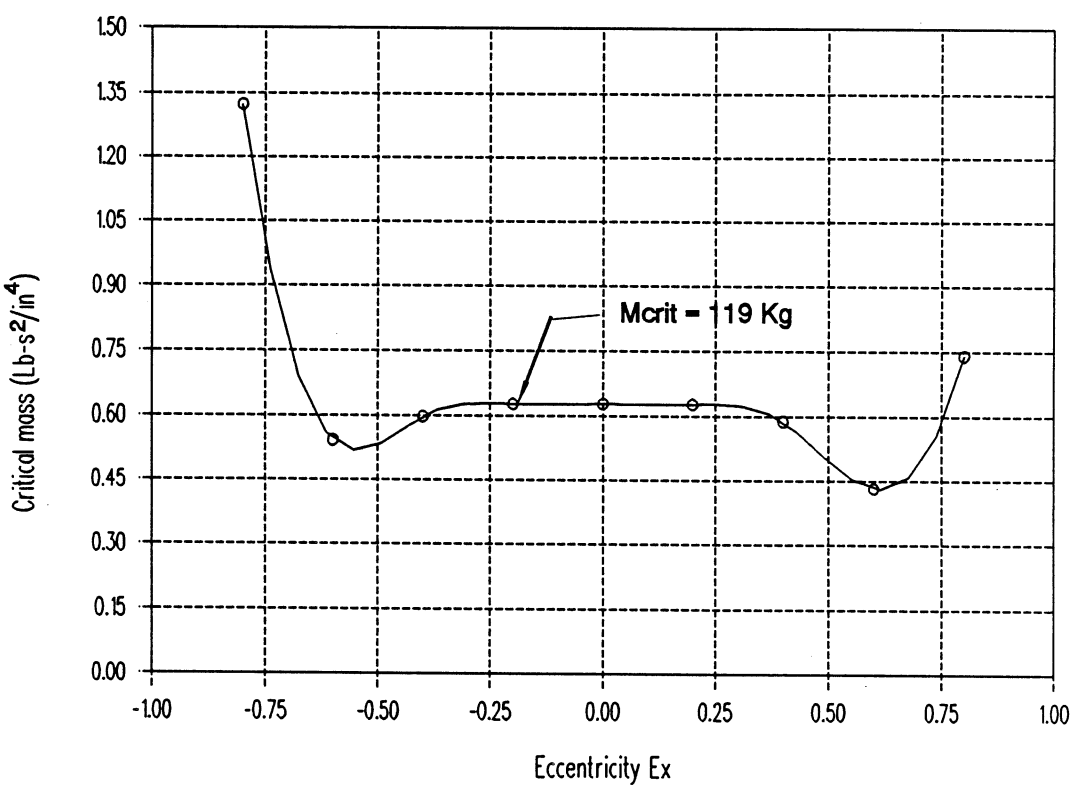

Figure 32 Critical mass versus eccentricity ratio

7.0 OPERATING ENVIRONMENT

7.1 Compilation and memory requirements

The computer code ICYL1 has been written to run under a variety of operating environments. Executable versions of the ICYL1 have been compiled with VERSION 5.0 of the Microsoft FORTRAN compiler and tested for use on IBM PC compatible computers with 80x87 floating point coprocessors.

All source files constituting the source program have been compiled and linked as follows:

```
fl /c /Gt /414 /AH ICYL.FOR
fl /c /Gt /414 /AH ICYLPT2.FOR
fl /c /Gt /414 /AH INPCHK.FOR
fl /c /Gt /414 /AH COL.FOR
fl /c /Gt /414 /AH MISC.FOR
fl /c /Gt /414 /AH QFS.FOR
fl /c /Gt /414 /AH SOLVE.FOR
fl /c /Gt /414 /AH ZINT.FOR

fl /Lp ICYL COL ICYLPT2 INPCHK MISC QFS SOLVE ZINT
   /link c:\for5\llibf7p c:\OS2\DOSCALLS,ICYL1 DEF /SE:256

Rename ICYL.EXE ICYL1.EXE
```

Note that all integers are forced to INTEGER*4 with the 4l4 switch.

The executable file is renamed to be consistent with the CFD Executive Program.

A program definition file is required when running this program in order to define the program as a PM text window compatible (VIO) program. The following file named "ICYL1.DEF" must be used:

```
NAME          ICYL1   WINDOWCOMPAT
DESCRIPTION   'ICYL1 Analysis Program'
STUB          'OS2STUB.EXE'
```

```
DATA         MULTIPLE
STACKSIZE    16384
HEAPSIZE     4096
PROTMODE
EXPORTS
```

The memory required to run the program is controlled by the values of the parameters MAXMEM in the included file BMEM.FOR at the time of compilation. This file contains the line:

```
PARAMETER (MAXMEM=20000)
```

where MAXMEM represents the maximum allowable number of REAL*8 elements to be used by the program's arrays with two or more dimensions. It requires 503k of available memory. The DOS version of the program should run on any IBM PC or compatible with a math coprocessor, sufficient memory and DOS 4.0 or higher.

Under the OS/2 operating system, the following command should be used:

```
PARAMETER (MAXMEM = 20,000)
```

The program has been compiled and tested under OS2.

7.2 Error messages

Following are descriptions of the error messages produced by the program. If the error number is positive, the program execution stops with a FORTRAN message of: "Return code 1" to the user's screen. If the error number is negative, the program execution continues with the next case in the input file. The fields underlined in the descriptions below are variable and depend on the program inputs. The output messages are written to the output file, except when an input file is not found (error number 11), in which case the message is written to the user screen.

Error number	Description
1	FORTRAN error number: 6511 reading namelist namelist variable name not found The user should carefully check the names of each variable specified in the namelist, and if the problem reoccurs, place arrays after variables
2	Variable out of range the following variable: N has a value outside of program limits Consult program documentation.
2	Variable out of range the following variable: N2(1) has a value outside of program limits Consult program documentation.
3	NEGATIVE FILM THICKNESS REQUESTED BY THE FOLLOWING VALUES OF EX, EY, ALFA, BETA: 1.10000 .100000 .000000 .000000 SUGGESTED USER ACTION: ● REDUCE THE SPECIFIED APPLIED FORCES/MOMENTS ● REDUCE THE SPECIFIED ECCENTRICITY/MISALIGNMENT This warns the user that the prescribed displacements and/or misalignments exceed allowable limits and should be reduced. If this message occurs during iterations for rotor position, the new guess is outside of the domain limited by that of solid contact with he housing, and either the applied forces/moments should be reduced or increased more slowly from previous cases.
-4	*** WARNING *** ***ITERATION LIMIT:NIT(2)=_____ reached in iteration for pressure distribution Occurs when the Newton-Raphson iteration procedure for finding the pressure distribution does not converge to within a relative error of ECR(2) in NIT(2) iterations.

RECOMMENDED USER ACTION: Increase NIT(2), ECR(2), or try using the more refined velocity component calculations with IFRIC=4. If this fails, try using a finer grid.

-5

*** WARNING *** NIT(3)=______
Maximum variable Y error =_______
Maximum equation error =________

Maximum number of outer iteration loop reached. Occurs when the Newton-Raphson iteration procedure for finding the rotor position and pocket pressures does not converge to within a relative error of ECR(3) in NIT(3) iterations.
RECOMMENDED USER ACTION: Increase NIT(3), ECR(3), or try a different guess for position and/or pocket pressures.

6

Consecutive diverging iterations
RECOMMENDED USER ACTION: Increase MAXDIT.
If preceded by:

MAXDIT=______ exceeded
MAXIMUM ERROR=________

it is in the outer iterations for position and pocket pressures, and the user should try changing rotor displacements or applied forces more gradually. If preceded by:

dpmax=______

it is in the iterations for pressure and the user should try to refine the mesh.

7

Moments cannot be specified with ISYM=1

9

u,v iteration limit reached NIT(1)
NUMBER OF ITERATIONS: NIT(1)=____
ERROR CRITERIA: ECR(1)=_________
Try: increasing NIT(1) or increasing ECR(1), or using the more refined velocity component calculations with IFRIC=4.

-10

*** ALLOCATION ERROR: REQUESTED MEMORY= DDDDDDD
EXCEEDS: DDDDD
Decrease M or N, or use version of program with larger MAXMEM

11

Cannot fine input file: ICYL.INP

11

= Illegal Output file
= Error opening file: XXXX.XXX

---

14 Internal error in program

Zero flow in pocket

i1 = 1

This error should not normally occur.
If it does, check to see if inputs are correct.

---

16 DETERMINANT=0 at J=_____

This error would occur in the highly unlikely event that a singular matrix was encountered during the column method solution for the pressures.

The following error messages, without assigned numbers, occur during I/O to the saved pressure distribution files (ISAVEP>0 or IREADP>0):

Error writing to file:________
The user should check that sufficient disk space is available.

Error or EOF reading from file:_______

Mismatch in mesh size
M, N, NPOCK=____________
Previously saved file:_______ has:
MFILE, NFILE, NPOCKF=_____________

The user should check that the mesh size, number of pockets and their location match with the case that generated the saved file.

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APPENDIX A

Input and Output Listings
for Sample Problems

Listing of sample EX1

```
  Incompressible CYLindrical seal program (ICYL)
TIME:18:19:01   DATE:10/24/91 INPUT FILE:ICYLEX1
 &INPUTS
 TITLE='90 DEGREE SECTOR: CALCULATE ORIFICE'
 CREF=0.001, RPMJ=1000, XMU=1.E-6, RHO=1.E-4,
 RADIUS=       1.000000, LENGTH=      4.000000, TE=     90.000000,
 PCAV=-1000, PSUP=100, IPER=0,
 NPOCK=  1,  PPOCK= 50,
             M1=   2,   M2=   4,
             N1=   3,   N2=   9,
 /

 &INPUTS
 TITLE='90 DEGREE SECTOR: CALCULATE ECCENTRIC MISALIGNED FORCES & MOMENTS'
 EX=0.1, BETA=0.1,
 /
```

```
 90 DEGREE SECTOR: CALCULATE ORIFICE

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000     inches
 Seal Length =   4.0000     inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =   .00000     inches
 Housing Roughness =   .00000     inches
 Rotor Angular Velocity =   1000.0     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Inertia pressure drop coefficient =  1.0000

                          Left        Right
 Pressure at top    =   .00000      .00000     psi
 Pressure at bottom =   .00000      .00000     psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  10

 Data for   1 pressurized pockets:
 Supply pressure =   100.00     psi
 Discharge Coeff. =  .60000

Pocket           Axial    Circumferential        Pressure
Number        Start   End      Start   End        (psi          )
  1              2     4          3     9           50.000

 Pressure scale P0=  100.00     psi
 Dimensionless parameters:
    Speed of rotor surface            XLj=  6.2832
    Speed of housing surface          XLb=  .00000
    Inertia pressure drop coefficient XLI= 3.47222E-05
    Couette Reynolds numbers          Re0=  10.472
    Poisseuille Reynolds numbers      Re0s=  10.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
  Orifice diameter calculated:
  dorif=  1.376969541898273E-002
```

```
                              Outputs:

Pressure:    1            2            3            4            5
   1   .0000000     .0000000     .0000000     .0000000     .0000000
   2   .0000000     24.68445     24.98811     24.68445     .0000000
   3   .0000000     49.97046     49.99120     49.97046     .0000000
   4   .0000000     49.99911     50.00000     49.99911     .0000000
   5   .0000000     49.99913     50.00000     49.99913     .0000000
   6   .0000000     49.99913     50.00000     49.99913     .0000000
   7   .0000000     49.99913     50.00000     49.99913     .0000000
   8   .0000000     49.99911     50.00000     49.99911     .0000000
   9   .0000000     49.97046     49.99120     49.97046     .0000000
  10   .0000000     24.68445     24.98811     24.68445     .0000000
  11   .0000000     .0000000     .0000000     .0000000     .0000000

                               x             y
Rotor Eccentricity ratio=    .00000        .00000
Rotor Misalignment ratio=    .00000        .00000
Force components       =    -124.30       -124.30      lbs
Moment components      =  -2.84196E-15   3.14965E-15 in-lb

                        Location
Maximum pressure       ( 3,  4)=     50.000      psi
Minimum film thickness ( 1,  1)=    1.00000E-03 inches

 Pressurized Pockets:                 Orifice diameter = 1.37697E-02 inches

Pocket              Pressure              Flow
Number              (psi          )    (in**3/sec      )
   1                 50.000            8.93490E-02
                                     ____________
                Total=               8.93490E-02

Axial flow from left=   -5.22690E-03 in**3/sec
Axial flow  to right=    5.22690E-03 in**3/sec
circumferential flow at start =   -5.22690E-03 in**3/sec
circumferential flow at   end =   -5.22690E-03 in**3/sec
Overall flow error  =    2.96059E-17 in**3/sec
Torque about z-axis =     .46058     in-lb
Power loss          =    48.232      in-lb/sec

Running time =    54.870 sec
```

```
  Pressures & velocities written to file:icylex1.888

 90 DEGREE SECTOR: CALCULATE ECCENTRIC MISALIGNED FORCES & MOMENTS

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =    4.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =    1000.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Inertia pressure drop coefficient =   1.0000

                         Left         Right
 Pressure at top    =   .00000       .00000       psi
 Pressure at bottom =   .00000       .00000       psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =    4
 Number of circumferential grid intervals =  10
```

```
 Data for    1 pressurized pockets:
 Orifice diameter =  1.37697E-02 inches
 Supply pressure =   100.00      psi
 Discharge Coeff. =  .60000

Pocket            Axial    Circumferential       Pressure
Number          Start   End     Start   End       (psi            )
  1                2     4        3      9          50.000

 Pressure scale P0=  100.00      psi
 Dimensionless parameters:
    Speed of rotor surface             XLj=  6.2832
    Speed of housing surface           XLb=  .00000
    Inertia pressure drop coefficient  XLI= 3.47222E-05
    Couette Reynolds numbers           Re0=  10.472
    Poisseuille Reynolds numbers       ReOs=  10.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

```
                                    Outputs:

 Pressure:    1              2              3              4              5
    1   .0000000       .0000000       .0000000       .0000000       .0000000
    2   .0000000       24.84610       25.13419       24.79428       .0000000
    3   .0000000       50.39195       50.41090       50.40089       .0000000
    4   .0000000       50.41601       50.41687       50.41644       .0000000
    5   .0000000       50.41602       50.41687       50.41641       .0000000
    6   .0000000       50.41602       50.41687       50.41637       .0000000
    7   .0000000       50.41601       50.41687       50.41632       .0000000
    8   .0000000       50.41599       50.41687       50.41624       .0000000
    9   .0000000       50.38645       50.40766       50.38602       .0000000
   10   .0000000       24.20086       23.80112       22.79851       .0000000
   11   .0000000       .0000000       .0000000       .0000000       .0000000

                                   x              y
Rotor Eccentricity ratio=       .10000         .00000
Rotor Misalignment ratio=       .00000         .10000
Force components        =      -125.21        -124.69      lbs
Moment components       =      -.21829        4.09901E-02 in-lb

                          Location
Maximum pressure        (  3,   4)=    50.417      psi
Minimum film thickness (  5,   1)=    8.00000E-04 inches

 Pressurized Pockets:                      Orifice diameter = 1.37697E-02 inches

Pocket                 Pressure                  Flow
Number                 (psi          )        (in**3/sec      )
   1                    50.417                8.89758E-02
                                             ___________
               Total=                        8.89758E-02

Axial flow from left=    -5.00579E-03 in**3/sec
Axial flow  to right=     3.65389E-03 in**3/sec
circumferential flow at start =    -5.00579E-03 in**3/sec
circumferential flow at   end =    -5.00579E-03 in**3/sec
Overall flow error  =     1.85037E-17 in**3/sec
Torque about z-axis =       .48663      in-lb
Power loss          =      50.960       in-lb/sec

Running time =    216.460 sec
```

```
  Pressures & velocities written to file:icylex1.888

 Total running time:     272.810 sec
```

Listing of sample EX2

```
  Incompressible CYLindrical seal program (ICYL)
TIME:18:23:37   DATE:10/24/91 INPUT FILE:ICYLEX2
 &INPUTS
 TITLE='90 DEGREE SECTOR: CALCULATE ECCENTRIC MISALIGNED POSITION',
 CREF=0.001, RPMJ=1000, XMU=1.E-6, RHO=1.E-4,
 RADIUS=        1.000000, LENGTH=        4.000000, TE=      90.000000,
 PCAV=-1000, PSUP=100, IPER=0,  ireadp=1, kdiag=95,
  dorif=  1.376969541898273E-002, MAXDIT=2,
 FXG= 125.21
 FYG= 124.69
 MXG= .21829
 MYG= -4.09901E-02
 NPOCK=  1,  PPOCK= 50,
             M1=   2,   M2=   4,
             N1=   3,   N2=   9,
 /
```

```
 90 DEGREE SECTOR: CALCULATE ECCENTRIC MISALIGNED POSITION

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =   1.0000     inches
 Seal Length =   4.0000     inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =   .00000     inches
 Housing Roughness =   .00000     inches
 Rotor Angular Velocity =   1000.0     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Inertia pressure drop coefficient =  1.0000

                          Left        Right
 Pressure at top    =   .00000       .00000      psi
 Pressure at bottom =   .00000       .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =    4
 Number of circumferential grid intervals =  10

 Data for   1 pressurized pockets:
 Orifice diameter =  1.37697E-02 inches
 Supply pressure =   100.00      psi
 Discharge Coeff. =  .60000

Pocket              Axial     Circumferential        Pressure
Number          Start   End      Start    End        (psi           )
  1                 2     4          3      9          50.000

 Pressure scale P0=  100.00      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  6.2832
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 3.47222E-05
    Couette Reynolds numbers            Re0=  10.472
    Poisseuille Reynolds numbers        Re0s=  10.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
  Pressures & velocities read from file:icylex1.888

  EQUATION ERRORS:
             .908345E-02    .388345E-02    .218290E-02   -.409901E-03
             .273300E-15
  INCREMENTS:
             .100585       -.516513E-02    .197244E-01    .495881E-01
             .410370E-02
```

```
            EX              EY              ALFA            BETA
            PPOCK  1
          .100585       -.516513E-02    .197244E-01     .495881E-01
          .504104
EQUATION ERRORS:
          .365070E-03    .176299E-03    .769522E-05     .259626E-03
         -.152581E-01
INCREMENTS:
         -.647448E-03    .493284E-02   -.200427E-01     .480501E-03
          .795572E-04
            EX              EY              ALFA            BETA
            PPOCK  1
          .999375E-01   -.232288E-03   -.318274E-03     .500686E-01
          .504183
EQUATION ERRORS:
         -.741666E-05    .596926E-06   -.154115E-05    -.279301E-05
         -.789866E-03
INCREMENTS:
         -.187861E-03    .242019E-03    .353738E-03    -.618298E-04
         -.533761E-05
            EX              EY              ALFA            BETA
            PPOCK  1
          .997497E-01    .973033E-05    .354634E-04     .500068E-01
          .504178
```

```
                              Outputs:

Pressure:    1             2             3             4             5
    1    .0000000      .0000000      .0000000      .0000000      .0000000
    2    .0000000      24.84681      25.13495      24.79498      .0000000
    3    .0000000      50.39285      50.41182      50.40180      .0000000
    4    .0000000      50.41693      50.41779      50.41736      .0000000
    5    .0000000      50.41694      50.41779      50.41733      .0000000
    6    .0000000      50.41694      50.41779      50.41729      .0000000
    7    .0000000      50.41693      50.41779      50.41724      .0000000
    8    .0000000      50.41691      50.41779      50.41716      .0000000
    9    .0000000      50.38738      50.40858      50.38694      .0000000
   10    .0000000      24.20490      23.80517      22.80258      .0000000
   11    .0000000      .0000000      .0000000      .0000000      .0000000

                                x             y
Rotor Eccentricity ratio=   9.97497E-02   9.73033E-06
Rotor Misalignment ratio=   7.09267E-05    .10001
Force components       =    -125.21       -124.69      lbs
Moment components      =    -.21829       4.09901E-02  in-lb

                         Location
Maximum pressure       (  3,   4)=    50.418      psi
Minimum film thickness (  5,   1)=    8.00237E-04 inches

 Pressurized Pockets:                  Orifice diameter = 1.37697E-02 inches

Pocket              Pressure              Flow
Number              (psi          )    (in**3/sec      )
   1                 50.418            8.89750E-02
                                      ____________
               Total=                  8.89750E-02

Axial flow from left=   -5.00790E-03 in**3/sec
Axial flow  to right=    3.65625E-03 in**3/sec
circumferential flow at start =    -5.00790E-03 in**3/sec
circumferential flow at   end =    -5.00790E-03 in**3/sec
Overall flow error  =     .00000      in**3/sec
Torque about z-axis =     .48657      in-lb
Power loss          =     50.953      in-lb/sec

Running-time =   687.170 sec
```

```
Pressures & velocities written to file:icylex2.888

Total running time:    688.210 sec
```

Listing of sample EX3

```
  Incompressible CYLindrical seal program (ICYL)
TIME:18:35:09   DATE:10/24/91 INPUT FILE:ICYLEX3
 &INPUTS
 TITLE='90 DEG SECTOR: CALCULATE ANGLULAR POSITION FOR ZERO MOMENTS',
 CREF=0.001, RPMJ=1000, XMU=1.E-6, RHO=1.E-4,
 RADIUS=       1.000000, LENGTH=       4.000000, TE=     90.000000,
 PCAV=-1000, PSUP=100, IPER=0,
  dorif=  1.37696954189827E-002, MAXDIT=2,
 EX=  0.1,  EY= 0.0,
 MXG= 0.0, MYG= 0.0
 NPOCK=  1,  PPOCK= 50,
            M1=   2,   M2=   4,
            N1=   3,   N2=   9,
 I1F(1)=1, I2F(1)=5, J1F(1)=1, J2F(1)=11, delta(1,1)=-0.0003, delta(2,1)=0.0006/

 &INPUTS EX=0.3/
 &INPUTS EX=0.5/
```

```
 90 DEG SECTOR: CALCULATE ANGLULAR POSITION FOR ZERO MOMENTS

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =   1.0000     inches
 Seal Length =   4.0000     inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =   .00000     inches
 Housing Roughness =   .00000     inches
 Rotor Angular Velocity =   1000.0     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Inertia pressure drop coefficient =  1.0000

                          Left        Right
 Pressure at top    =   .00000      .00000      psi
 Pressure at bottom =   .00000      .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  10

 Data for   1 pressurized pockets:
 Orifice diameter =  1.37697E-02 inches
 Supply pressure =   100.00     psi
 Discharge Coeff. =  .60000

Pocket           Axial    Circumferential        Pressure
Number         Start  End      Start   End        (psi           )
  1              2     4         3     9           50.000

 Pressure scale P0=  100.00     psi
 Dimensionless parameters:
    Speed of rotor surface           XLj=  6.2832
    Speed of housing surface         XLb=  .00000
    Inertia pressure drop coefficient XLI= 3.47222E-05
    Couette Reynolds numbers         Re0=  10.472
    Poisseuille Reynolds numbers     Re0s=  10.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

```
                               Outputs:

 Pressure:    1              2              3              4              5
    1    .0000000       .0000000       .0000000       .0000000       .0000000
    2    .0000000       23.93747       24.27055       23.96725       .0000000
    3    .0000000       48.68494       48.68976       48.66309       .0000000
    4    .0000000       48.69527       48.69547       48.69409       .0000000
    5    .0000000       48.69527       48.69547       48.69408       .0000000
    6    .0000000       48.69526       48.69547       48.69402       .0000000
    7    .0000000       48.69525       48.69547       48.69394       .0000000
    8    .0000000       48.69524       48.69547       48.69378       .0000000
    9    .0000000       48.67943       48.68662       48.64563       .0000000
   10    .0000000       22.66937       22.96793       22.70857       .0000000
   11    .0000000       .0000000       .0000000       .0000000       .0000000

                                   x              y
Rotor Eccentricity ratio=       .10000         .00000
Rotor Misalignment ratio=    -1.75241E-02    4.96843E-02
Force components        =     -120.92        -120.42      lbs
Moment components       =     3.06203E-09   -1.31766E-08 in-lb

                          Location
Maximum pressure       ( 3,  4)=     48.695      psi
Minimum film thickness ( 1,  1)=    6.49684E-04 inches

 Pressurized Pockets:                  Orifice diameter = 1.37697E-02 inches

Pocket              Pressure              Flow
Number              (psi          )    (in**3/sec     )
   1                 48.695             9.05071E-02
                                       ____________
                Total=                 9.05071E-02

Axial flow from left=   -2.07808E-03 in**3/sec
Axial flow  to right=    7.25414E-03 in**3/sec
circumferential flow at start =   -2.07808E-03 in**3/sec
circumferential flow at   end =   -2.07808E-03 in**3/sec
Overall flow error  =   -6.29126E-17 in**3/sec
Torque about z-axis =      .50182      in-lb
Power loss          =     52.551      in-lb/sec

Running time =   542.060 sec
```

```
  Pressures & velocities written to file:icylex3.888

 90 DEG SECTOR: CALCULATE ANGLULAR POSITION FOR ZERO MOMENTS

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =   4.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =    1000.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Inertia pressure drop coefficient =   1.0000

                          Left        Right
 Pressure at top    =   .00000      .00000      psi
 Pressure at bottom =   .00000      .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =    4
 Number of circumferential grid intervals =   10
```

```
Data for   1 pressurized pockets:
Orifice diameter =  1.37697E-02 inches
Supply pressure =   100.00      psi
Discharge Coeff. =  .60000

Pocket            Axial    Circumferential        Pressure
Number         Start   End     Start   End        (psi            )
 1               2      4        3      9          48.695

Pressure scale P0=  100.00      psi
Dimensionless parameters:
   Speed of rotor surface               XLj=  6.2832
   Speed of housing surface             XLb=  .00000
   Inertia pressure drop coefficient XLI= 3.47222E-05
   Couette Reynolds numbers             Re0=  10.472
   Poisseuille Reynolds numbers         Re0s=  10.000

Friction formula based on Moody diagram (Nelson)
 Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	.0000000	.0000000	.0000000	.0000000
2	.0000000	22.71523	22.96621	22.72714	.0000000
3	.0000000	47.25910	47.26172	47.25384	.0000000
4	.0000000	47.26370	47.26380	47.26337	.0000000
5	.0000000	47.26369	47.26380	47.26330	.0000000
6	.0000000	47.26368	47.26380	47.26318	.0000000
7	.0000000	47.26366	47.26380	47.26303	.0000000
8	.0000000	47.26364	47.26380	47.26278	.0000000
9	.0000000	47.24808	47.25489	47.21446	.0000000
10	.0000000	19.07614	19.27468	19.11030	.0000000
11	.0000000	.0000000	.0000000	.0000000	.0000000

```
                                x              y
Rotor Eccentricity ratio=     .30000         .00000
Rotor Misalignment ratio=   -7.13971E-05     .17489
Force components        =    -116.90        -115.46      lbs
Moment components       =   -8.04523E-09    4.10135E-08 in-lb

                         Location
Maximum pressure        ( 3,  4)=     47.264       psi
Minimum film thickness (  1,  1)=   5.74895E-04 inches

Pressurized Pockets:                   Orifice diameter = 1.37697E-02 inches

Pocket              Pressure                Flow
Number              (psi            )     (in**3/sec       )
   1                 47.264                9.17612E-02
                                         ------------
                 Total=                 9.17612E-02

Axial flow from left=   -1.43968E-03 in**3/sec
Axial flow  to right=    4.20502E-03 in**3/sec
circumferential flow at start =    -1.43968E-03 in**3/sec
circumferential flow at   end =    -1.43968E-03 in**3/sec
Overall flow error  =    2.96059E-17 in**3/sec
Torque about z-axis =      .56995      in-lb
Power loss          =     59.685       in-lb/sec

Running time =   686.230 sec
```

```
Pressures & velocities written to file:icylex3.888

90 DEG SECTOR: CALCULATE ANGLULAR POSITION FOR ZERO MOMENTS

Input values:
```

```
Seal Type: Cylindrical seal
Rotor Radius =   1.0000      inches
Seal Length =   4.0000      inches
Clearance =  1.00000E-03 inches
Rotor Roughness =   .00000      inches
Housing Roughness =   .00000      inches
Rotor Angular Velocity =   1000.0      r/min.
Housing Angular Velocity =   .00000      r/min.
Inertia pressure drop coefficient =  1.0000

                         Left        Right
Pressure at top    =   .00000      .00000     psi
Pressure at bottom =   .00000      .00000     psi
Viscosity =  1.00000E-06 psi-sec
Density =  1.00000E-04 lb-s**2/in**4

Number of axial grid intervals =   4
Number of circumferential grid intervals =  10

Data for    1 pressurized pockets:
Orifice diameter =  1.37697E-02 inches
Supply pressure =   100.00      psi
Discharge Coeff. =  .60000

Pocket            Axial     Circumferential        Pressure
Number         Start   End     Start   End        (psi            )
 1                2     4          3     9          47.264

Pressure scale P0=  100.00      psi
Dimensionless parameters:
   Speed of rotor surface            XLj=  6.2832
   Speed of housing surface          XLb=  .00000
   Inertia pressure drop coefficient XLI= 3.47222E-05
   Couette Reynolds numbers          Re0=  10.472
   Poisseuille Reynolds numbers      Re0s=  10.000

Friction formula based on Moody diagram (Nelson)
 Newton-Raphson itertions for velocity components
 i=          1j=          3
************************************
* ICYL error number          3
************************************
 NEGATIVE FILM THICKNESS REQUESTED
 BY THE FOLLOWING VALUES OF EX, EY, ALFA, BETA:
   .500000         .000000         1.00000         .000000
SUGGESTED USER ACTION:
o REDUCE THE SPECIFIED APPLIED FORCES/MOMENTS
o REDUCE THE SPECIFIED ECCENTRICITY/MISALIGMENT
```

Listing for sample F3

```
  Incompressible CYLindrical seal program (ICYL)
TIME:18:55:43   DATE:10/24/91 INPUT FILE:ICYLF3
 &INPUTS
 TITLE='RALEIGH STEP WITH VARIABLE DEPTH'
 CREF=0.001, LENGTH=2.0, RADIUS=4, TE= 120,
 RHO=1.05E-04, XMU=0.26E-07, RPMJ= 1000,
 ISYM=1, IPER=0, M=9, N=61,
 DZT= 0.5, 0.5, 0.5, 0.5, 1, 1, 2, 4,
 I1F(1)= 4, I2F(1)= 9, J1F(1)=  1, J2F(1)= 40,
 delta(1,1)= 0.002, delta(3,1)= -0.001/

 &INPUTS ISTOP=1/
```

```
 RALEIGH STEP WITH VARIABLE DEPTH

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    4.0000      inches
 Seal Length =    2.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =   1000.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Symmetry at seal midlength
 Inertia pressure drop coefficient =  1.0000

                          Left        Right
 Pressure at top    =    .00000      .00000      psi
 Pressure at bottom =    .00000      .00000      psi
 Viscosity =  2.60000E-08 psi-sec
 Density =  1.05000E-04 lb-s**2/in**4

 Number of axial grid intervals =    8
 Number of circumferential grid intervals =  60

 Pressure scale P0=  261.38      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  1.0000
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 8.81056E-03
    Couette Reynolds numbers            Re0=  1691.6
    Poisseuille Reynolds numbers        Re0s=  10150.

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5	6	7	8	9
1	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
2	.0000000	.7590057E-01	.1530027	.2326623	.2391723	.2504795	.2599336	.2736867	.2838555
3	.0000000	.1424310	.2860616	.4321105	.4441487	.4654894	.4835642	.5102839	.5302887
4	.0000000	.1996071	.4002627	.6030153	.6199186	.6501453	.6759293	.7144676	.7436802
5	.0000000	.2486057	.4981119	.7494171	.7706243	.8087288	.8413742	.8905326	.9281946
6	.0000000	.2905816	.5819327	.8748208	.8998459	.9449461	.9836956	1.042347	1.087676
7	.0000000	.3265565	.6537675	.9822858	1.010709	1.062040	1.106230	1.173365	1.225614

8	.0000000	.3574272	.7154078	1.074494	1.105956	1.162859	1.211917	1.286652	1.345141
9	.0000000	.3839825	.7684291	1.153803	1.187999	1.249916	1.303354	1.384931	1.449063
10	.0000000	.4069181	.8142213	1.222294	1.258969	1.325430	1.382840	1.470621	1.539883
11	.0000000	.4268511	.8540167	1.281810	1.320754	1.391376	1.452419	1.545879	1.619845
12	.0000000	.4443319	.8889146	1.333998	1.375043	1.449516	1.513925	1.612642	1.690968
13	.0000000	.4598563	.9199054	1.380340	1.423357	1.501446	1.569014	1.672668	1.755091
14	.0000000	.4738771	.9478930	1.422187	1.467086	1.548625	1.619206	1.727571	1.813908
15	.0000000	.4868145	.9737168	1.460794	1.507521	1.592412	1.665921	1.778864	1.869009
16	.0000000	.4990673	.9981727	1.497354	1.545892	1.634103	1.710515	1.827997	1.921923
17	.0000000	.5110237	1.022036	1.533024	1.583393	1.674965	1.754314	1.876396	1.974158
18	.0000000	.5230721	1.046081	1.568964	1.621225	1.716271	1.798659	1.925502	2.027246
19	.0000000	.5356132	1.071109	1.606369	1.660628	1.759343	1.844942	1.976823	2.082790
20	.0000000	.5490724	1.097968	1.646509	1.702920	1.805589	1.894653	2.031975	2.142517
21	.0000000	.5639139	1.127584	1.690768	1.749540	1.856556	1.949429	2.092743	2.208340
22	.0000000	.5806556	1.160992	1.740691	1.802102	1.913975	2.011111	2.161141	2.282422
23	.0000000	.5998872	1.199368	1.798037	1.862440	1.979829	2.081809	2.239483	2.367259
24	.0000000	.6222900	1.244071	1.864837	1.932681	2.056418	2.163978	2.330474	2.465770
25	.0000000	.6486601	1.296691	1.943467	2.015313	2.146440	2.260506	2.437304	2.581415
26	.0000000	.6799354	1.359099	2.036724	2.113273	2.253094	2.374821	2.563773	2.718324
27	.0000000	.7172270	1.433513	2.147922	2.230045	2.380183	2.511013	2.714436	2.881467
28	.0000000	.7618553	1.522568	2.281001	2.369782	2.532258	2.673989	2.894781	3.076849
29	.0000000	.8153925	1.629403	2.440653	2.537439	2.714771	2.869649	3.111443	3.311762
30	.0000000	.8797113	1.757754	2.632468	2.738937	2.934269	3.105109	3.372477	3.595095
31	.0000000	.9570397	1.912072	2.863097	2.981346	3.198619	3.388961	3.687689	3.937717
32	.0000000	1.050024	2.097638	3.140444	3.273102	3.517280	3.731608	4.069079	4.352973
33	.0000000	1.161796	2.320710	3.473871	3.624252	3.901634	4.145674	4.531408	4.857315
34	.0000000	1.296042	2.588654	3.874413	4.046727	4.365382	4.646543	5.092993	5.471119
35	.0000000	1.457036	2.910035	4.354954	4.554593	4.925036	5.253106	5.776856	6.219755
36	.0000000	1.649500	3.294433	4.930136	5.164115	5.600514	5.988927	6.612502	7.134991
37	.0000000	1.877583	3.750860	5.615102	5.892862	6.415918	6.884529	7.638818	8.256774
38	.0000000	2.139964	4.280300	6.418899	6.755149	7.401453	7.983382	8.908986	9.635329
39	.0000000	2.404459	4.834631	7.307842	7.746907	8.604488	9.360582	10.49832	11.33277
40	.0000000	2.473825	5.074714	7.966061	8.838489	10.16306	11.17924	12.51240	13.42078
41	.0000000	1.561764	3.075072	4.472524	5.615044	7.329957	8.587707	10.18674	11.23365
42	.0000000	1.045867	2.063316	3.024621	3.905977	5.408211	6.600409	8.214671	

```
      9.304622
43    .0000000    .7515861        1.489420        2.200810        2.875314        4.092544        5.115081        6.591065
      7.642062
44    .0000000    .5645495        1.121736        1.664642        2.187197        3.156440        3.999578        5.276296
      6.235623
45    .0000000    .4349318        .8654131        1.287175        1.696290        2.466183        3.150227        4.220510
      5.062967
46    .0000000    .3400205        .6770878        1.008330        1.331030        1.943292        2.494405        3.375619
      4.095612
47    .0000000    .2681388        .5341886        .7961010        1.051906        1.539615        1.982207        2.700084
      3.303715
48    .0000000    .2125472        .4235533        .6314997        .8349113        1.223894        1.578735        2.159737
      2.658920
49    .0000000    .1689735        .3367787        .5022611        .6642924        .9747333        1.258885        1.727075
      2.135772
50    .0000000    .1345097        .2681185        .3999342        .5290820        .7768251        1.004094        1.380141
      1.712222
51    .0000000    .1070716        .2134411        .3184125        .4213016        .6188330        .8003087        1.101444
      1.369598
52    .0000000    .8510838E-01    .1696666        .2531290        .3349581        .4921425        .6366950        .8770284
      1.092321
53    .0000000    .6743507E-01    .1344385        .2005817        .2654426        .3900783        .5047757        .6957263
      .8675095
54    .0000000    .5312795E-01    .1059181        .1580349        .2091476        .3073894        .3978393        .5485604
      .6845607
55    .0000000    .4145532E-01    .8264822E-01    .1233181        .1632077        .2398910        .3105147        .4282726
      .5347542
56    .0000000    .3182909E-01    .6345732E-01    .9468516E-01    .1253157        .1842062        .2384548        .3289480
      .4108967
57    .0000000    .2376925E-01    .4738880E-01    .7070996E-01    .9358596E-01    .1375709        .1780948        .2457134
      .3070097
58    .0000000    .1687669E-01    .3364725E-01    .5020623E-01    .6644954E-01    .9768303E-01    .1264617        .1744914
      .2180601
59    .0000000    .1081181E-01    .2155568E-01    .3216412E-01    .4257049E-01    .6258107E-01    .8102001E-01    .1117973
      .1397280
60    .0000000   .5276688E-02   .1052024E-01   .1569772E-01   .2077663E-01   .3054311E-01   .3954284E-01   .5456570E-01
      .6820240E-01
61    .0000000    .0000000        .0000000        .0000000        .0000000        .0000000        .0000000        .0000000
      .0000000

                                   x              y
Rotor Eccentricity ratio=       .00000         .00000
Rotor Misalignment ratio=       .00000         .00000
Force components        =      -15.944        -34.108       lbs
Moment components       =       .00000         .00000       in-lb

                          Location
Maximum pressure        (  9, 40)=      13.421      psi
Minimum film thickness  (  1,  1)=    1.00000E-03 inches

Axial flow from left=     -.32760      in**3/sec
Axial flow  to right=    5.64050E-13  in**3/sec
circumferential flow at start =    -.32760      in**3/sec
circumferential flow at   end =    -.32760      in**3/sec
Overall flow error  =   -7.65414E-02  in**3/sec
Torque about z-axis =     .65179      in-lb
Power loss          =    68.255       in-lb/sec

Running time =  1690.770 sec
```

```
 Pressures & velocities written to file:icylf3.888

 Total running time:    1693.960 sec
```

Listing of sample F4

```
  Incompressible CYLindrical seal program (ICYL)
TIME:19:24:01   DATE:10/24/91 INPUT FILE:ICYLF4
 &INPUTS
 TITLE='TEST OF AXIAL FILM TAPER'
 CREF=0.001, LENGTH=2.0, RADIUS=4, Ey=0.5, TE= 120,
 RHO=1.05E-04, XMU=0.26E-06, RPMJ= 1000,
 IPER=0, M=7, N=61,
 I1F(1)= 4, I2F(1)= 7, J1F(1)=  1, J2F(1)= 61, delta(2,1)= 0.001/
```

```
 TEST OF AXIAL FILM TAPER

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    4.0000     inches
 Seal Length =    2.0000     inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000     inches
 Housing Roughness =    .00000     inches
 Rotor Angular Velocity =    1000.0     r/min.
 Housing Angular Velocity =    .00000     r/min.
 Inertia pressure drop coefficient =  1.0000

                          Left        Right
 Pressure at top    =   .00000      .00000      psi
 Pressure at bottom =   .00000      .00000      psi
 Viscosity =  2.60000E-07 psi-sec
 Density =  1.05000E-04 lb-s**2/in**4

 Number of axial grid intervals =   6
 Number of circumferential grid intervals =  60

 Pressure scale P0=  2613.8      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  1.0000
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 8.81056E-04
    Couette Reynolds numbers            Re0=  169.16
    Poisseuille Reynolds numbers        Re0s=  1015.0

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5	6	7
1	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
2	.0000000	4.389630	5.667830	4.648945	2.646207	1.180036	.0000000
3	.0000000	7.857097	10.33662	8.508960	4.847228	2.135926	.0000000
4	.0000000	10.67154	14.22616	11.73867	6.681287	2.917200	.0000000
5	.0000000	13.01661	17.51314	14.46658	8.216053	3.560762	.0000000
6	.0000000	15.02056	20.33666	16.79625	9.508208	4.094787	.0000000
7	.0000000	16.77463	22.80480	18.81044	10.60424	4.541098	.0000000
8	.0000000	18.34463	25.00083	20.57471	11.54168	4.916718	.0000000
9	.0000000	19.77837	26.98834	22.14043	12.35041	5.234939	.0000000
10	.0000000	21.11065	28.81543	23.54737	13.05393	5.506111	.0000000
11	.0000000	22.36664	30.51794	24.82585	13.67043	5.738234	.0000000
12	.0000000	23.56416	32.12204	25.99845	14.21377	5.937428	.0000000
13	.0000000	24.71540	33.64613	27.08154	14.69429	6.108304	.0000000
14	.0000000	25.82798	35.10230	28.08634	15.11944	6.254260	.0000000
15	.0000000	26.90592	36.49751	29.01989	15.49436	6.377725	.0000000
16	.0000000	27.95013	37.83441	29.88580	15.82231	6.480359	.0000000
17	.0000000	28.95894	39.11200	30.68481	16.10504	6.563205	.0000000
18	.0000000	29.92841	40.32616	31.41534	16.34312	6.626827	.0000000
19	.0000000	30.85257	41.47003	32.07380	16.53616	6.671416	.0000000
20	.0000000	31.72363	42.53434	32.65500	16.68303	6.696878	.0000000

21	.0000000	32.53217	43.50769	33.15241	16.78206	6.702907	.0000000
22	.0000000	33.26727	44.37680	33.55839	16.83113	6.689051	.0000000
23	.0000000	33.91670	45.12677	33.86448	16.82790	6.654767	.0000000
24	.0000000	34.46707	45.74133	34.06159	16.76986	6.599463	.0000000
25	.0000000	34.90406	46.20311	34.14030	16.65444	6.522543	.0000000
26	.0000000	35.21261	46.49401	34.09100	16.47918	6.423443	.0000000
27	.0000000	35.37726	46.59551	33.90424	16.24177	6.301669	.0000000
28	.0000000	35.38245	46.48911	33.57096	15.94018	6.156823	.0000000
29	.0000000	35.21289	46.15685	33.08276	15.57272	5.988636	.0000000
30	.0000000	34.85400	45.58177	32.43224	15.13819	5.797000	.0000000
31	.0000000	34.29244	44.74860	31.61330	14.63594	5.581991	.0000000
32	.0000000	33.51658	43.64432	30.62145	14.06597	5.343901	.0000000
33	.0000000	32.51715	42.25895	29.45421	13.42904	5.083269	.0000000
34	.0000000	31.28780	40.58624	28.11143	12.72674	4.800906	.0000000
35	.0000000	29.82580	38.62449	26.59571	11.96166	4.497934	.0000000
36	.0000000	28.13272	36.37735	24.91274	11.13745	4.175825	.0000000
37	.0000000	26.21510	33.85473	23.07178	10.25902	3.836441	.0000000
38	.0000000	24.08523	31.07365	21.08610	9.332624	3.482094	.0000000
39	.0000000	21.76194	28.05931	18.97353	8.366121	3.115609	.0000000
40	.0000000	19.27151	24.84616	16.75706	7.369181	2.740409	.0000000
41	.0000000	16.64883	21.47931	14.46564	6.353590	2.360618	.0000000
42	.0000000	13.93881	18.01626	12.13514	5.333616	1.981186	.0000000
43	.0000000	11.19842	14.52906	9.809591	4.326471	1.608056	.0000000
44	.0000000	8.499606	11.10743	7.542879	3.352865	1.248354	.0000000
45	.0000000	5.933638	7.862769	5.400836	2.437659	.9106379	.0000000
46	.0000000	3.617825	4.933734	3.464090	1.610592	.6051947	.0000000
47	.0000000	1.705905	2.493450	1.831743	.9070063	.3444262	.0000000
48	.0000000	.4045478	.7586344	.6262475	.3683846	.1433614	.0000000
49	.0000000	.0000000	.0000000	.0000000	.4232981E-01	.2041278E-01	.0000000
50	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
51	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
52	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
53	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
54	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
55	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
56	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
57	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
58	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
59	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
60	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000
61	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000	.0000000

```
                              x              y
Rotor Eccentricity ratio=   .00000         .50000
Rotor Misalignment ratio=   .00000         .00000
Force components        =  -132.41        -135.21     lbs
Moment components       =  -28.653         25.786     in-lb

                        Location
Maximum pressure        ( 3, 27)=    46.596     psi
Minimum film thickness ( 1, 46)=    5.00000E-04 inches

Axial flow from left=   -4.65672E-02 in**3/sec
Axial flow  to right=     .10257     in**3/sec
circumferential flow at start =   -4.65672E-02 in**3/sec
circumferential flow at   end =   -4.65672E-02 in**3/sec
Overall flow error  =   -2.06889E-02 in**3/sec
Torque about z-axis =     9.4622     in-lb
Power loss          =     990.87     in-lb/sec

Running time =   449.570 sec
```

```
 Pressures & velocities written to file:icylf4.888

 Total running time:    452.250 sec
```

Listing of sample F9

```
  Incompressible CYLindrical seal program (ICYL)
TIME:19:31:37   DATE:10/24/91 INPUT FILE:ICYLF9
 &INPUTS
 TITLE='3-LOBE SEAL PRELOAD= 0.2',
 CREF=0.001, LENGTH=2.0, RADIUS=4,
 RHO=1.05E-04, XMU=0.26E-07, RPMJ= 1000,
 ISYM=1, IPER=0, M=5, N=73, ISTIFF=2,
 I1F(1)= 1, I2F(1)= 5, J1F(1)=  1, J2F(1)=  2, delta(1,1)= 0.001,
 I1F(2)= 1, I2F(2)= 5, J1F(2)=  3, J2F(2)= 23, delta(4,2)= 0.2,
 I1F(3)= 1, I2F(3)= 5, J1F(3)= 24, J2F(3)= 26, delta(1,3)= 0.001,
 I1F(4)= 1, I2F(4)= 5, J1F(4)= 27, J2F(4)= 47, delta(4,4)= 0.2,
 I1F(5)= 1, I2F(5)= 5, J1F(5)= 48, J2F(5)= 50, delta(1,5)= 0.001,
 I1F(6)= 1, I2F(6)= 5, J1F(6)= 51, J2F(6)= 71, delta(4,6)= 0.2,
 I1F(7)= 1, I2F(7)= 5, J1F(7)= 72, J2F(7)= 73, delta(1,7)= 0.001/

 &INPUTS delta(4,2)= 0.5, delta(4,4)= 0.5, delta(4,6)= 0.5,
 TITLE='3-LOBE SEAL PRELOAD= 0.5'/

 &INPUTS delta(4,2)= 0.8, delta(4,4)= 0.8, delta(4,6)= 0.8,
 TITLE='3-LOBE SEAL PRELOAD= 0.8'/

 &INPUTS ISTOP=1/
```

```
 3-LOBE SEAL PRELOAD= 0.2

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    4.0000      inches
 Seal Length =   2.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =   .00000      inches
 Rotor Angular Velocity =    1000.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Symmetry at seal midlength
 Inertia pressure drop coefficient =   1.0000

                          Left         Right
 Pressure at top    =   .00000       .00000      psi
 Pressure at bottom =   .00000       .00000      psi
 Viscosity =  2.60000E-08 psi-sec
 Density =  1.05000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  72

 Pressure scale P0=  261.38      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  1.0000
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 8.81056E-03
    Couette Reynolds numbers            Re0=  1691.6
    Poisseuille Reynolds numbers        Re0s=  10150.

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	.0000000	.0000000	.0000000	.0000000
2	.0000000	3.466386	5.387893	6.368042	6.667573
3	.0000000	3.513879	5.669133	6.831791	7.198529
4	.0000000	2.194814	3.803068	4.759788	5.075445
5	.0000000	1.532222	2.698837	3.419685	3.662591

6	.0000000	1.140423	2.006947	2.546362	2.729220
7	.0000000	.8807199	1.541815	1.951622	2.090426
8	.0000000	.6902278	1.202006	1.517096	1.623509
9	.0000000	.5367393	.9311580	1.172629	1.253962
10	.0000000	.4035490	.6989417	.8793254	.9400074
11	.0000000	.2830987	.4912619	.6187505	.6616992
12	.0000000	.1740847	.3052780	.3868483	.4145230
13	.0000000	.8060801E-01	.1475526	.1912955	.2064518
14	.0000000	.1376888E-01	.3505980E-01	.5147395E-01	.5747668E-01
15	.0000000	.0000000	.0000000	.0000000	.0000000
16	.0000000	.0000000	.0000000	.0000000	.0000000
17	.0000000	.0000000	.0000000	.0000000	.0000000
18	.0000000	.0000000	.0000000	.0000000	.0000000
19	.0000000	.0000000	.0000000	.0000000	.0000000
20	.0000000	.0000000	.0000000	.0000000	.0000000
21	.0000000	.0000000	.0000000	.0000000	.0000000
22	.0000000	.0000000	.0000000	.0000000	.0000000
23	.0000000	.0000000	.0000000	.0000000	.0000000
24	.0000000	.0000000	.0000000	.0000000	.0000000
25	.0000000	.0000000	.0000000	.0000000	.0000000
26	.0000000	3.456406	5.371054	6.346345	6.644082
27	.0000000	3.507635	5.657922	6.817287	7.182859
28	.0000000	2.191174	3.796403	4.751122	5.066079
29	.0000000	1.530074	2.694881	3.414527	3.657012
30	.0000000	1.139152	2.004601	2.543299	2.725907
31	.0000000	.8799680	1.540426	1.949808	2.088463
32	.0000000	.6897839	1.201186	1.516025	1.622349
33	.0000000	.5364780	.9306752	1.171998	1.253280
34	.0000000	.4033958	.6986587	.8789557	.9396072
35	.0000000	.2830097	.4910975	.6185357	.6614667
36	.0000000	.1740341	.3051844	.3867260	.4143906
37	.0000000	.8058081E-01	.1475023	.1912299	.2063808
38	.0000000	.1375708E-01	.3503798E-01	.5144544E-01	.5744582E-01
39	.0000000	.0000000	.0000000	.0000000	.0000000
40	.0000000	.0000000	.0000000	.0000000	.0000000
41	.0000000	.0000000	.0000000	.0000000	.0000000
42	.0000000	.0000000	.0000000	.0000000	.0000000
43	.0000000	.0000000	.0000000	.0000000	.0000000
44	.0000000	.0000000	.0000000	.0000000	.0000000
45	.0000000	.0000000	.0000000	.0000000	.0000000
46	.0000000	.0000000	.0000000	.0000000	.0000000
47	.0000000	.0000000	.0000000	.0000000	.0000000
48	.0000000	.0000000	.0000000	.0000000	.0000000
49	.0000000	.0000000	.0000000	.0000000	.0000000
50	.0000000	3.456406	5.371054	6.346345	6.644082
51	.0000000	3.507635	5.657922	6.817287	7.182859
52	.0000000	2.191174	3.796403	4.751122	5.066079
53	.0000000	1.530074	2.694881	3.414527	3.657012
54	.0000000	1.139152	2.004601	2.543299	2.725907
55	.0000000	.8799680	1.540426	1.949808	2.088463
56	.0000000	.6897839	1.201186	1.516025	1.622349
57	.0000000	.5364780	.9306752	1.171998	1.253280
58	.0000000	.4033958	.6986587	.8789557	.9396072
59	.0000000	.2830097	.4910975	.6185357	.6614667
60	.0000000	.1740341	.3051844	.3867260	.4143906
61	.0000000	.8058081E-01	.1475023	.1912299	.2063808
62	.0000000	.1375708E-01	.3503798E-01	.5144544E-01	.5744582E-01
63	.0000000	.0000000	.0000000	.0000000	.0000000
64	.0000000	.0000000	.0000000	.0000000	.0000000
65	.0000000	.0000000	.0000000	.0000000	.0000000
66	.0000000	.0000000	.0000000	.0000000	.0000000
67	.0000000	.0000000	.0000000	.0000000	.0000000
68	.0000000	.0000000	.0000000	.0000000	.0000000
69	.0000000	.0000000	.0000000	.0000000	.0000000
70	.0000000	.0000000	.0000000	.0000000	.0000000
71	.0000000	.0000000	.0000000	.0000000	.0000000
72	.0000000	.0000000	.0000000	.0000000	.0000000
73	.0000000	.0000000	.0000000	.0000000	.0000000

```
                               x                  y
Rotor Eccentricity ratio=     .00000            .00000
Rotor Misalignment ratio=     .00000            .00000
Force components        =   -2.65654E-02    -5.84936E-03 lbs
Moment components       =     .00000            .00000     in-lb

                        Location
Maximum pressure      (  5,  3)=     7.1985     psi
Minimum film thickness (  1, 13)=   8.00000E-04 inches

Axial flow from left=    -.26533     in**3/sec
Axial flow  to right=   -4.87871E-02 in**3/sec
circumferential flow at start =    -.26533     in**3/sec
circumferential flow at   end =    -.26533     in**3/sec
Overall flow error  =    -.32484     in**3/sec
Torque about z-axis =     2.5892     in-lb
Power loss          =     271.14     in-lb/sec

Dynamic Coefficients ( Force unit / displacement unit )
Disp.           x             y             α             β
              inches        inches        radians       radians       Force unit

Kx           47979.        93834.                                     lbs
Ky          -96811.        46981.                                     lbs

Bx           1785.9        -14.999                                    lbs-sec
By           5.1411         1831.2                                    lbs-sec

Critical mass       =     16.903     lb-sec**2/in
Threshold Frequency=      52.704      rad./sec

Running time =  2409.090 sec
```

```
  Pressures & velocities written to file:icylf9.888

 3-LOBE SEAL PRELOAD= 0.5

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    4.0000      inches
 Seal Length =    2.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =    1000.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Symmetry at seal midlength
 Inertia pressure drop coefficient =  1.0000

                          Left         Right
 Pressure at top    =    .00000       .00000      psi
 Pressure at bottom =    .00000       .00000      psi
 Viscosity =  2.60000E-08 psi-sec
 Density =  1.05000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  72

 Pressure scale P0=  261.38      psi
 Dimensionless parameters:
    Speed of rotor surface               XLj=  1.0000
    Speed of housing surface             XLb=  .00000
    Inertia pressure drop coefficient XLI= 8.81056E-03
    Couette Reynolds numbers             Re0=  1691.6
    Poisseuille Reynolds numbers         Re0s=  10150.

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	.0000000	.0000000	.0000000	.0000000
2	.0000000	4.156681	6.612974	7.923391	8.331922
3	.0000000	7.338594	11.40814	13.48882	14.13027
4	.0000000	5.922446	9.994412	12.32748	13.08397
5	.0000000	5.378091	9.218590	11.50206	12.25776
6	.0000000	5.058526	8.674414	10.83988	11.56037
7	.0000000	4.748007	8.125056	10.14517	10.81742
8	.0000000	4.349038	7.429043	9.267268	9.878440
9	.0000000	3.813909	6.509326	8.116076	8.650007
10	.0000000	3.131393	5.347667	6.670313	7.110111
11	.0000000	2.326844	3.988254	4.985850	5.318599
12	.0000000	1.465171	2.543103	3.202848	3.424942
13	.0000000	.6555762	1.197662	1.550178	1.671965
14	.0000000	.6723736E-01	.2217943	.3473268	.3938491
15	.0000000	.0000000	.0000000	.0000000	.0000000
16	.0000000	.0000000	.0000000	.0000000	.0000000
17	.0000000	.0000000	.0000000	.0000000	.0000000
18	.0000000	.0000000	.0000000	.0000000	.0000000
19	.0000000	.0000000	.0000000	.0000000	.0000000
20	.0000000	.0000000	.0000000	.0000000	.0000000
21	.0000000	.0000000	.0000000	.0000000	.0000000
22	.0000000	.0000000	.0000000	.0000000	.0000000
23	.0000000	.0000000	.0000000	.0000000	.0000000
24	.0000000	.0000000	.0000000	.0000000	.0000000
25	.0000000	.0000000	.0000000	.0000000	.0000000
26	.0000000	4.144821	6.593423	7.898299	8.304763
27	.0000000	7.330111	11.39308	13.46943	14.10934
28	.0000000	5.917321	9.985065	12.31535	13.07087
29	.0000000	5.374945	9.212803	11.49453	12.24961
30	.0000000	5.056590	8.670843	10.83522	11.55533
31	.0000000	4.746820	8.122864	10.14231	10.81433
32	.0000000	4.348315	7.427707	9.265522	9.876551
33	.0000000	3.813472	6.508519	8.115021	8.648865
34	.0000000	3.131131	5.347184	6.669682	7.109429
35	.0000000	2.326690	3.987970	4.985479	5.318197
36	.0000000	1.465083	2.542941	3.202636	3.424712
37	.0000000	.6555290	1.197575	1.550064	1.671842
38	.0000000	.6721707E-01	.2217568	.3472778	.3937960
39	.0000000	.0000000	.0000000	.0000000	.0000000
40	.0000000	.0000000	.0000000	.0000000	.0000000
41	.0000000	.0000000	.0000000	.0000000	.0000000
42	.0000000	.0000000	.0000000	.0000000	.0000000
43	.0000000	.0000000	.0000000	.0000000	.0000000
44	.0000000	.0000000	.0000000	.0000000	.0000000
45	.0000000	.0000000	.0000000	.0000000	.0000000
46	.0000000	.0000000	.0000000	.0000000	.0000000
47	.0000000	.0000000	.0000000	.0000000	.0000000
48	.0000000	.0000000	.0000000	.0000000	.0000000
49	.0000000	.0000000	.0000000	.0000000	.0000000
50	.0000000	4.144821	6.593423	7.898299	8.304763
51	.0000000	7.330111	11.39308	13.46943	14.10934
52	.0000000	5.917321	9.985065	12.31535	13.07087
53	.0000000	5.374945	9.212803	11.49453	12.24961
54	.0000000	5.056590	8.670843	10.83522	11.55533
55	.0000000	4.746820	8.122864	10.14231	10.81433
56	.0000000	4.348315	7.427707	9.265522	9.876551
57	.0000000	3.813472	6.508519	8.115021	8.648865
58	.0000000	3.131131	5.347184	6.669682	7.109429
59	.0000000	2.326690	3.987970	4.985479	5.318197
60	.0000000	1.465083	2.542941	3.202636	3.424712
61	.0000000	.6555290	1.197575	1.550064	1.671842
62	.0000000	.6721707E-01	.2217568	.3472778	.3937960
63	.0000000	.0000000	.0000000	.0000000	.0000000
64	.0000000	.0000000	.0000000	.0000000	.0000000

```
   65   .0000000      .0000000      .0000000      .0000000      .0000000
   66   .0000000      .0000000      .0000000      .0000000      .0000000
   67   .0000000      .0000000      .0000000      .0000000      .0000000
   68   .0000000      .0000000      .0000000      .0000000      .0000000
   69   .0000000      .0000000      .0000000      .0000000      .0000000
   70   .0000000      .0000000      .0000000      .0000000      .0000000
   71   .0000000      .0000000      .0000000      .0000000      .0000000
   72   .0000000      .0000000      .0000000      .0000000      .0000000
   73   .0000000      .0000000      .0000000      .0000000      .0000000

                                 x              y
Rotor Eccentricity ratio=     .00000          .00000
Rotor Misalignment ratio=     .00000          .00000
Force components        =   -3.49877E-02   -8.31832E-03 lbs
Moment components       =     .00000          .00000      in-lb

                        Location
Maximum pressure       (  5,  3)=     14.130      psi
Minimum film thickness (  1, 13)=    5.00000E-04 inches

Axial flow from left=     -.35121      in**3/sec
Axial flow  to right=   -6.24718E-02  in**3/sec
circumferential flow at start =    -.35121      in**3/sec
circumferential flow at   end =    -.35121      in**3/sec
Overall flow error  =     -.41802      in**3/sec
Torque about z-axis =      3.7183      in-lb
Power loss          =      389.38      in-lb/sec

Dynamic Coefficients ( Force unit / displacement unit )
Disp.             x            y             α             β
                inches       inches       radians       radians       Force unit

Kx          2.89980E+05  2.92443E+05                                  lbs
Ky         -2.96694E+05  2.88381E+05                                  lbs

Bx           5685.4       -22.486                                     lbs-sec
By           7.7065        5748.3                                     lbs-sec

Critical mass       =     108.63      lb-sec**2/in
Threshold Frequency=      51.526       rad./sec

Running time =  2242.390 sec
-----------------------------------------------------------------------------
  Pressures & velocities written to file:icylf9.888

 3-LOBE SEAL PRELOAD= 0.8

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    4.0000       inches
 Seal Length =    2.0000       inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =     .00000       inches
 Housing Roughness =     .00000       inches
 Rotor Angular Velocity =     1000.0       r/min.
 Housing Angular Velocity =     .00000       r/min.
 Symmetry at seal midlength
 Inertia pressure drop coefficient =   1.0000

                          Left          Right
 Pressure at top     =   .00000        .00000       psi
 Pressure at bottom =    .00000        .00000       psi
 Viscosity =  2.60000E-08 psi-sec
 Density =  1.05000E-04 lb-s**2/in**4

 Number of axial grid intervals =    4
 Number of circumferential grid intervals =   72
```

```
Pressure scale P0=  261.38     psi
Dimensionless parameters:
   Speed of rotor surface           XLj=  1.0000
   Speed of housing surface         XLb=  .00000
   Inertia pressure drop coefficient XLI= 8.81056E-03
   Couette Reynolds numbers         Re0=  1691.6
   Poisseuille Reynolds numbers     Re0s=  10150.

Friction formula based on Moody diagram (Nelson)
 Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	.0000000	.0000000	.0000000	.0000000
2	.0000000	4.997707	8.102573	9.803959	10.33879
3	.0000000	11.98120	18.36983	21.57735	22.55892
4	.0000000	17.93122	29.63813	36.19392	38.30096
5	.0000000	24.58486	41.25281	50.86924	54.00841
6	.0000000	31.65560	53.30825	65.90481	70.03662
7	.0000000	38.70494	65.18802	80.61294	85.67707
8	.0000000	44.76781	75.31160	93.07666	98.90598
9	.0000000	48.22805	81.01977	100.0570	106.2988
10	.0000000	47.06888	79.03274	97.58465	103.6677
11	.0000000	39.75268	66.92261	82.77358	87.98566
12	.0000000	26.65269	45.44243	56.64006	60.36131
13	.0000000	11.22625	20.29806	26.17023	28.19186
14	.0000000	.0000000	1.391577	3.207206	3.904947
15	.0000000	.0000000	.0000000	.0000000	.0000000
16	.0000000	.0000000	.0000000	.0000000	.0000000
17	.0000000	.0000000	.0000000	.0000000	.0000000
18	.0000000	.0000000	.0000000	.0000000	.0000000
19	.0000000	.0000000	.0000000	.0000000	.0000000
20	.0000000	.0000000	.0000000	.0000000	.0000000
21	.0000000	.0000000	.0000000	.0000000	.0000000
22	.0000000	.0000000	.0000000	.0000000	.0000000
23	.0000000	.0000000	.0000000	.0000000	.0000000
24	.0000000	.0000000	.0000000	.0000000	.0000000
25	.0000000	.0000000	.0000000	.0000000	.0000000
26	.0000000	4.984120	8.081154	9.777017	10.30985
27	.0000000	11.97094	18.35212	21.55491	22.53484
28	.0000000	17.92467	29.62631	36.17870	38.28456
29	.0000000	24.58054	41.24489	50.85895	53.99731
30	.0000000	31.65271	53.30294	65.89788	70.02913
31	.0000000	38.70302	65.18447	80.60830	85.67205
32	.0000000	44.76653	75.30924	93.07358	98.90265
33	.0000000	48.22721	81.01823	100.0550	106.2966
34	.0000000	47.06835	79.03176	97.58337	103.6663
35	.0000000	39.75235	66.92201	82.77280	87.98481
36	.0000000	26.65250	45.44208	56.63960	60.36081
37	.0000000	11.22616	20.29788	26.16998	28.19159
38	.0000000	.0000000	1.391499	3.207105	3.904836
39	.0000000	.0000000	.0000000	.0000000	.0000000
40	.0000000	.0000000	.0000000	.0000000	.0000000
41	.0000000	.0000000	.0000000	.0000000	.0000000
42	.0000000	.0000000	.0000000	.0000000	.0000000
43	.0000000	.0000000	.0000000	.0000000	.0000000
44	.0000000	.0000000	.0000000	.0000000	.0000000
45	.0000000	.0000000	.0000000	.0000000	.0000000
46	.0000000	.0000000	.0000000	.0000000	.0000000
47	.0000000	.0000000	.0000000	.0000000	.0000000
48	.0000000	.0000000	.0000000	.0000000	.0000000
49	.0000000	.0000000	.0000000	.0000000	.0000000
50	.0000000	4.984120	8.081154	9.777017	10.30985
51	.0000000	11.97094	18.35212	21.55491	22.53484
52	.0000000	17.92467	29.62631	36.17870	38.28456
53	.0000000	24.58054	41.24489	50.85895	53.99731
54	.0000000	31.65271	53.30294	65.89788	70.02913

55	.0000000	38.70302	65.18447	80.60830	85.67205
56	.0000000	44.76653	75.30924	93.07358	98.90265
57	.0000000	48.22721	81.01823	100.0550	106.2966
58	.0000000	47.06835	79.03176	97.58337	103.6663
59	.0000000	39.75235	66.92201	82.77280	87.98481
60	.0000000	26.65250	45.44208	56.63960	60.36081
61	.0000000	11.22616	20.29788	26.16998	28.19159
62	.0000000	.0000000	1.391499	3.207105	3.904836
63	.0000000	.0000000	.0000000	.0000000	.0000000
64	.0000000	.0000000	.0000000	.0000000	.0000000
65	.0000000	.0000000	.0000000	.0000000	.0000000
66	.0000000	.0000000	.0000000	.0000000	.0000000
67	.0000000	.0000000	.0000000	.0000000	.0000000
68	.0000000	.0000000	.0000000	.0000000	.0000000
69	.0000000	.0000000	.0000000	.0000000	.0000000
70	.0000000	.0000000	.0000000	.0000000	.0000000
71	.0000000	.0000000	.0000000	.0000000	.0000000
72	.0000000	.0000000	.0000000	.0000000	.0000000
73	.0000000	.0000000	.0000000	.0000000	.0000000

```
                              x               y
Rotor Eccentricity ratio=     .00000          .00000
Rotor Misalignment ratio=     .00000          .00000
Force components        =   -4.33646E-02    -1.15971E-02 lbs
Moment components       =     .00000          .00000     in-lb

                         Location
Maximum pressure       ( 5,  9)=      106.30      psi
Minimum film thickness ( 1, 13)=    2.00000E-04 inches

Axial flow from left=     -.42541       in**3/sec
Axial flow  to right=    -7.47190E-02 in**3/sec
circumferential flow at start =    -.42541      in**3/sec
circumferential flow at   end =    -.42541      in**3/sec
Overall flow error  =     -.50430       in**3/sec
Torque about z-axis =      7.2848       in-lb
Power loss          =      762.87       in-lb/sec

Dynamic Coefficients ( Force unit / displacement unit )
Disp.          x            y            α            ß
             inches       inches      radians      radians      Force unit

Kx         5.29188E+06  2.52767E+06                             lbs
Ky        -2.53197E+06  5.29061E+06                             lbs

Bx           51439.       -13.517                               lbs-sec
By          -9.8654        51527.                               lbs-sec

Critical mass      =      2191.3      lb-sec**2/in
Threshold Frequency=      49.139       rad./sec

Running time =  2253.920 sec
```

```
  Pressures & velocities written to file:icylf9.888

 Total running time:    6911.770 sec
```

Listing of sample I1

```
  Incompressible CYLindrical seal program (ICYL)
TIME:07:21:50   DATE:10/26/91 INPUT FILE:ICYLI1
 &INPUTS
 TITLE='4-POCKET SEAL: CALCULATION OF ORIFICE DIAMETER'
 CREF=0.001, RADIUS=1., LENGTH=1., RPMJ=3600., PSUP=400, PCAV=-1000,
 XMU=1.E-6, RHO=1.E-4,
 M=5, N=61, ISYM=1,
 NPOCK=4, M1=  3,  3,  3,  3,
          M2=  5,  5,  5,  5,
          N1=  3, 18, 33, 48,
          N2= 14, 29, 44, 59,
          PPOCK=4*200,
 /

 &INPUTS ISTOP=1/
```

```
 4-POCKET SEAL: CALCULATION OF ORIFICE DIAMETER

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000     inches
 Seal Length =   1.0000     inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =   .00000     inches
 Housing Roughness =   .00000     inches
 Rotor Angular Velocity =   3600.0     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Symmetry at seal midlength
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                          Left        Right
 Pressure at top    =   .00000      .00000     psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  60

 Data for   4 pressurized pockets:
 Supply pressure =   400.00     psi
 Discharge Coeff. =  .60000

Pocket            Axial    Circumferential         Pressure
Number          Start   End     Start   End        (psi            )
  1               3     5          3     14           200.00
  2               3     5         18     29           200.00
  3               3     5         33     44           200.00
  4               3     5         48     59           200.00

 Pressure scale P0=  400.00     psi
 Dimensionless parameters:
    Speed of rotor surface             XLj=  5.6549
    Speed of housing surface           XLb=  .00000
    Inertia pressure drop coefficient  XLI= 1.38889E-04
    Couette Reynolds numbers           Re0=  37.699
    Poisseuille Reynolds numbers       Re0s=  40.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
  Orifice diameter calculated:
  dorif=  1.452279376501468E-002
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	77.63210	142.0653	171.7143	179.8283
2	.0000000	82.26386	154.2718	179.2713	185.5231
3	.0000000	94.09363	199.4705	199.9862	199.9934
4	.0000000	98.00437	199.7689	200.0000	200.0000
5	.0000000	99.27607	199.7755	200.0000	200.0000
6	.0000000	99.68914	199.7774	200.0000	200.0000
7	.0000000	99.82211	199.7780	200.0000	200.0000
8	.0000000	99.86122	199.7781	200.0000	200.0000
9	.0000000	99.86122	199.7781	200.0000	200.0000
10	.0000000	99.82211	199.7780	200.0000	200.0000
11	.0000000	99.68914	199.7774	200.0000	200.0000
12	.0000000	99.27607	199.7755	200.0000	200.0000
13	.0000000	98.00437	199.7689	200.0000	200.0000
14	.0000000	94.09363	199.4705	199.9862	199.9934
15	.0000000	82.26386	154.2718	179.2713	185.5231
16	.0000000	77.63210	142.0653	171.7143	179.8283
17	.0000000	82.26386	154.2718	179.2713	185.5231
18	.0000000	94.09363	199.4705	199.9862	199.9934
19	.0000000	98.00437	199.7689	200.0000	200.0000
20	.0000000	99.27607	199.7755	200.0000	200.0000
21	.0000000	99.68914	199.7774	200.0000	200.0000
22	.0000000	99.82211	199.7780	200.0000	200.0000
23	.0000000	99.86122	199.7781	200.0000	200.0000
24	.0000000	99.86122	199.7781	200.0000	200.0000
25	.0000000	99.82211	199.7780	200.0000	200.0000
26	.0000000	99.68914	199.7774	200.0000	200.0000
27	.0000000	99.27607	199.7755	200.0000	200.0000
28	.0000000	98.00437	199.7689	200.0000	200.0000
29	.0000000	94.09363	199.4705	199.9862	199.9934
30	.0000000	82.26386	154.2718	179.2713	185.5231
31	.0000000	77.63210	142.0653	171.7143	179.8283
32	.0000000	82.26386	154.2718	179.2713	185.5231
33	.0000000	94.09363	199.4705	199.9862	199.9934
34	.0000000	98.00437	199.7689	200.0000	200.0000
35	.0000000	99.27607	199.7755	200.0000	200.0000
36	.0000000	99.68914	199.7774	200.0000	200.0000
37	.0000000	99.82211	199.7780	200.0000	200.0000
38	.0000000	99.86122	199.7781	200.0000	200.0000
39	.0000000	99.86122	199.7781	200.0000	200.0000
40	.0000000	99.82211	199.7780	200.0000	200.0000
41	.0000000	99.68914	199.7774	200.0000	200.0000
42	.0000000	99.27607	199.7755	200.0000	200.0000
43	.0000000	98.00437	199.7689	200.0000	200.0000
44	.0000000	94.09363	199.4705	199.9862	199.9934
45	.0000000	82.26386	154.2718	179.2713	185.5231
46	.0000000	77.63210	142.0653	171.7143	179.8283
47	.0000000	82.26386	154.2718	179.2713	185.5231
48	.0000000	94.09363	199.4705	199.9862	199.9934
49	.0000000	98.00437	199.7689	200.0000	200.0000
50	.0000000	99.27607	199.7755	200.0000	200.0000
51	.0000000	99.68914	199.7774	200.0000	200.0000
52	.0000000	99.82211	199.7780	200.0000	200.0000
53	.0000000	99.86122	199.7781	200.0000	200.0000
54	.0000000	99.86122	199.7781	200.0000	200.0000
55	.0000000	99.82211	199.7780	200.0000	200.0000
56	.0000000	99.68914	199.7774	200.0000	200.0000
57	.0000000	99.27607	199.7755	200.0000	200.0000
58	.0000000	98.00437	199.7689	200.0000	200.0000
59	.0000000	94.09363	199.4705	199.9862	199.9934
60	.0000000	82.26386	154.2718	179.2713	185.5231
61	.0000000	77.63210	142.0653	171.7143	179.8283

		x	y	
Rotor Eccentricity ratio	=	.00000	.00000	
Rotor Misalignment ratio	=	.00000	.00000	
Force components	=	-4.35708E-13	7.26762E-13	lbs
Moment components	=	.00000	.00000	in-lb

```
                          Location
Maximum pressure       (  4,   4)=     200.00      psi
Minimum film thickness (  1,   1)=    1.00000E-03 inches

 Pressurized Pockets:                  Orifice diameter = 1.45228E-02 inches

Pocket                   Pressure               Flow
Number                   (psi            )    (in**3/sec      )
    1                      200.00              9.93897E-02
    2                      200.00              9.93897E-02
    3                      200.00              9.93897E-02
    4                      200.00              9.93897E-02
                                            ____________
                Total=                      .39756

Axial flow from left=     -.39756     in**3/sec
Axial flow  to right=    9.25186E-18 in**3/sec
Overall flow error  =   -9.25186E-18 in**3/sec
Torque about z-axis =      1.5002     in-lb
Power loss          =      565.55     in-lb/sec

Running time =    531.080 sec
________________________________________________________________________________
  Pressures & velocities written to file:icyli1.888

 Total running time:     533.280 sec
```

Listing of sample I2

```
  Incompressible CYLindrical seal program (ICYL)
TIME:07:30:47   DATE:10/26/91 INPUT FILE:ICYLI2
 &INPUTS
 TITLE='4-POCKET SEAL: CALCULATION OF ECCENTRIC PERFORMANCE'
 CREF=0.001, RADIUS=1., LENGTH=1., RPMJ=3600., PSUP=400, PCAV=-1000,
 XMU=1.E-6, RHO=1.E-4,
 M=5, N=61, ISYM=1,
 EX=0.1, IREADP=1, ISTIFF=1,
 dorif=  1.4522793765E-02,
 NPOCK=4, M1=  3,  3,  3,  3,
          M2=  5,  5,  5,  5,
          N1=  3, 18, 33, 48,
          N2= 14, 29, 44, 59,
          PPOCK=4*200,
 /

 &INPUTS ISTOP=1/
```

```
 4-POCKET SEAL: CALCULATION OF ECCENTRIC PERFORMANCE

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =    1.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =    3600.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Symmetry at seal midlength
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                         Left         Right
 Pressure at top     =    .00000       .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =    4
 Number of circumferential grid intervals =   60

 Data for    4 pressurized pockets:
 Orifice diameter =  1.45228E-02 inches
 Supply pressure =   400.00      psi
 Discharge Coeff. =  .60000

Pocket           Axial     Circumferential         Pressure
Number        Start   End      Start    End         (psi           )
  1              3     5          3      14           200.00
  2              3     5         18      29           200.00
  3              3     5         33      44           200.00
  4              3     5         48      59           200.00

 Pressure scale P0=  400.00      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  5.6549
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 1.38889E-04
    Couette Reynolds numbers            Re0=  37.699
    Poisseuille Reynolds numbers        Re0s=  40.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
  Pressures & velocities read from file:ICYLI1.888
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	86.73388	158.7004	191.7653	200.8083
2	.0000000	89.74888	168.2434	195.6570	202.5430
3	.0000000	100.9913	213.8912	214.2692	214.2737
4	.0000000	104.5241	214.0970	214.2766	214.2766
5	.0000000	105.5227	214.0978	214.2766	214.2766
6	.0000000	105.7144	214.0947	214.2766	214.2766
7	.0000000	105.6598	214.0900	214.2766	214.2766
8	.0000000	105.5390	214.0842	214.2766	214.2766
9	.0000000	105.4019	214.0775	214.2766	214.2766
10	.0000000	105.2383	214.0699	214.2766	214.2766
11	.0000000	104.9637	214.0610	214.2766	214.2766
12	.0000000	104.3048	214.0497	214.2766	214.2766
13	.0000000	102.4307	214.0310	214.2766	214.2766
14	.0000000	96.82658	213.5791	214.2385	214.2509
15	.0000000	80.16927	153.7963	178.8474	185.0414
16	.0000000	71.05462	131.9385	160.0899	167.8037
17	.0000000	71.69048	135.8150	158.4753	164.1999
18	.0000000	79.88985	170.5856	170.9687	170.9725
19	.0000000	82.62081	170.7784	170.9740	170.9740
20	.0000000	83.56502	170.7758	170.9740	170.9740
21	.0000000	83.94216	170.7704	170.9740	170.9740
22	.0000000	84.14133	170.7645	170.9740	170.9740
23	.0000000	84.28482	170.7588	170.9740	170.9740
24	.0000000	84.40645	170.7534	170.9740	170.9740
25	.0000000	84.50238	170.7485	170.9740	170.9740
26	.0000000	84.52776	170.7439	170.9740	170.9740
27	.0000000	84.33597	170.7388	170.9740	170.9740
28	.0000000	83.47579	170.7297	170.9740	170.9740
29	.0000000	80.56427	170.4381	170.9634	170.9699
30	.0000000	71.54421	134.0630	156.0232	161.5443
31	.0000000	69.07081	126.4142	152.8427	160.0800
32	.0000000	74.82816	140.4627	163.1313	168.7745
33	.0000000	86.86943	184.5581	185.2222	185.2327
34	.0000000	90.97560	184.9614	185.2452	185.2452
35	.0000000	92.41006	184.9752	185.2452	185.2452
36	.0000000	92.97125	184.9831	185.2452	185.2452
37	.0000000	93.24527	184.9900	185.2452	185.2452
38	.0000000	93.42196	184.9971	185.2452	185.2452
39	.0000000	93.55955	185.0045	185.2452	185.2452
40	.0000000	93.66644	185.0123	185.2452	185.2452
41	.0000000	93.71357	185.0201	185.2452	185.2452
42	.0000000	93.59405	185.0273	185.2452	185.2452
43	.0000000	92.97092	185.0320	185.2452	185.2452
44	.0000000	90.79343	184.8687	185.2438	185.2452
45	.0000000	83.89610	154.0554	178.9418	185.2383
46	.0000000	84.14714	152.1203	183.2664	191.7807
47	.0000000	93.42003	173.8638	201.3474	208.1551
48	.0000000	109.6582	231.4847	232.1666	232.1782
49	.0000000	115.1139	231.9266	232.1956	232.1956
50	.0000000	116.8986	231.9463	232.1956	232.1956
51	.0000000	117.4523	231.9581	232.1956	232.1956
52	.0000000	117.5800	231.9672	232.1956	232.1956
53	.0000000	117.5451	231.9748	232.1956	232.1956
54	.0000000	117.4275	231.9813	232.1956	232.1956
55	.0000000	117.2326	231.9866	232.1956	232.1956
56	.0000000	116.8955	231.9905	232.1956	232.1956
57	.0000000	116.1869	231.9922	232.1956	232.1956
58	.0000000	114.3849	231.9886	232.1956	232.1956
59	.0000000	109.2529	231.7035	232.1797	232.1869
60	.0000000	94.08321	176.4599	204.7333	211.7670
61	.0000000	86.73388	158.7004	191.7653	200.8083

	x	y
Rotor Eccentricity ratio=	.10000	.00000
Rotor Misalignment ratio=	.00000	.00000

```
Force components        =    -65.335          26.457     lbs
Moment components       =     .00000          .00000     in-lb

                         Location
Maximum pressure      (  4, 49)=    232.20     psi
Minimum film thickness (  1,  1)=   9.00000E-04 inches

 Pressurized Pockets:                  Orifice diameter = 1.45228E-02 inches

Pocket               Pressure               Flow
Number               (psi            )    (in**3/sec      )
    1                 214.31              9.57678E-02
    2                 170.99               .10636
    3                 185.22               .10300
    4                 232.18              9.10441E-02
                                       ___________
                Total=                 .39616

Axial flow from left=    -.39616     in**3/sec
Axial flow  to right=    1.85037E-18 in**3/sec
Overall flow error  =    2.79349E-08 in**3/sec
Torque about z-axis =     1.5091     in-lb
Power loss          =     568.90     in-lb/sec

Dynamic Coefficients ( Force unit / displacement unit )
Disp.             x            y            α             ß
                inches       inches       radians       radians       Force unit

Kx          6.47344E+05  2.63998E+05                                  lbs
Ky         -2.65085E+05  6.56984E+05                                  lbs

Running time =  7783.380 sec
_______________________________________________________________________________
  Pressures & velocities written to file:icyli2.888

 Total running time:    7785.740 sec
```

Listing of sample I3

```
  Incompressible CYLindrical seal program (ICYL)
TIME:09:40:36   DATE:10/26/91 INPUT FILE:ICYLI3
 &INPUTS
 TITLE='4-POCKET SEAL: CALCULATION OF ECCENTRIC POSITION'
 CREF=0.001, RADIUS=1., LENGTH=1., RPMJ=3600., PSUP=400, PCAV=-1000,
 XMU=1.E-6, RHO=1.E-4,
 M=5, N=61, ISYM=1,
 EX=0.2, FXG= 65.335, FYG=-26.457,
  dorif=  1.452279376501468E-002
 NPOCK=4, M1=  3,  3,  3,  3,      NIT(3)=1,
          M2=  5,  5,  5,  5,
          N1=  3, 18, 33, 48,
          N2= 14, 29, 44, 59,
          PPOCK=4*200,
 /

 &INPUTS ISTOP=1/
```

```
 4-POCKET SEAL: CALCULATION OF ECCENTRIC POSITION

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =    1.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =    3600.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Symmetry at seal midlength
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                            Left        Right
 Pressure at top    =    .00000      .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  60

 Data for   4 pressurized pockets:
 Orifice diameter =  1.45228E-02 inches
 Supply pressure =   400.00      psi
 Discharge Coeff. =  .60000

Pocket              Axial     Circumferential        Pressure
Number          Start   End       Start   End        (psi               )
  1                 3     5           3    14          200.00
  2                 3     5          18    29          200.00
  3                 3     5          33    44          200.00
  4                 3     5          48    59          200.00

 Pressure scale P0=  400.00      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  5.6549
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 1.38889E-04
    Couette Reynolds numbers            Re0=  37.699
    Poisseuille Reynolds numbers        Re0s=  40.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
  Maximum variable Y error =  1.263000818896826E-001
  Maximum equation error =  1.573550962902160E-001
 ************************************
```

```
* ICYL error number         -5
************************************
 *** WARNING *** NIT(3)=          1
 Maximum number of outer iteration loop reached  before convergence
 RECOMMENDED USER ACTION:
 o Increase number of iterations NIT(3)
 o Apply the loads or displacements in smaller steps
    starting at the concentric aligned position
   (See IPAR in user's manual)
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	92.00202	168.2245	203.2485	212.8277
2	.0000000	94.20629	176.1844	204.9851	212.2409
3	.0000000	105.1440	221.5834	221.9891	221.9934
4	.0000000	108.5956	221.7985	221.9955	221.9955
5	.0000000	109.5782	221.7998	221.9955	221.9955
6	.0000000	109.7709	221.7972	221.9955	221.9955
7	.0000000	109.7198	221.7928	221.9955	221.9955
8	.0000000	109.6002	221.7874	221.9955	221.9955
9	.0000000	109.4615	221.7810	221.9955	221.9955
10	.0000000	109.2940	221.7738	221.9955	221.9955
11	.0000000	109.0159	221.7652	221.9955	221.9955
12	.0000000	108.3610	221.7543	221.9955	221.9955
13	.0000000	106.5171	221.7359	221.9955	221.9955
14	.0000000	101.0221	221.2867	221.9614	221.9737
15	.0000000	84.70113	161.8635	188.2992	194.8602
16	.0000000	76.37952	141.5478	171.6653	179.9167
17	.0000000	78.32840	148.3378	172.9105	179.0936
18	.0000000	88.19018	188.5859	189.0566	189.0620
19	.0000000	91.45791	188.8329	189.0653	189.0653
20	.0000000	92.56473	188.8308	189.0653	189.0653
21	.0000000	92.98435	188.8249	189.0653	189.0653
22	.0000000	93.18771	188.8182	189.0653	189.0653
23	.0000000	93.32314	188.8115	189.0653	189.0653
24	.0000000	93.43196	188.8053	189.0653	189.0653
25	.0000000	93.50990	188.7994	189.0653	189.0653
26	.0000000	93.50348	188.7938	189.0653	189.0653
27	.0000000	93.23738	188.7874	189.0653	189.0653
28	.0000000	92.17216	188.7756	189.0653	189.0653
29	.0000000	88.65541	188.4051	189.0488	189.0577
30	.0000000	77.85683	146.1958	170.0620	176.0406
31	.0000000	74.04143	135.5813	163.9540	171.7244
32	.0000000	79.08924	148.3331	172.3940	178.4037
33	.0000000	90.96533	192.7430	193.4303	193.4405
34	.0000000	95.00944	193.1483	193.4506	193.4506
35	.0000000	96.41685	193.1617	193.4506	193.4506
36	.0000000	96.96320	193.1690	193.4506	193.4506
37	.0000000	97.22668	193.1755	193.4506	193.4506
38	.0000000	97.39442	193.1821	193.4506	193.4506
39	.0000000	97.52379	193.1892	193.4506	193.4506
40	.0000000	97.62304	193.1966	193.4506	193.4506
41	.0000000	97.66346	193.2041	193.4506	193.4506
42	.0000000	97.53942	193.2112	193.4506	193.4506
43	.0000000	96.91823	193.2155	193.4506	193.4506
44	.0000000	94.76366	193.0416	193.4496	193.4506
45	.0000000	87.96695	161.6960	187.9772	194.6426
46	.0000000	88.92211	161.0424	194.1228	203.1685
47	.0000000	99.59100	185.8904	215.2834	222.5469
48	.0000000	117.6946	249.6508	250.4813	250.4960
49	.0000000	123.7866	250.1956	250.5200	250.5200
50	.0000000	125.7863	250.2191	250.5200	250.5200
51	.0000000	126.4194	250.2328	250.5200	250.5200
52	.0000000	126.5842	250.2433	250.5200	250.5200
53	.0000000	126.5743	250.2522	250.5200	250.5200
54	.0000000	126.4786	250.2597	250.5200	250.5200
55	.0000000	126.3026	250.2661	250.5200	250.5200

56	.0000000	125.9731	250.2709	250.5200	250.5200
57	.0000000	125.2330	250.2731	250.5200	250.5200
58	.0000000	123.2741	250.2686	250.5200	250.5200
59	.0000000	117.5943	249.9135	250.4985	250.5077
60	.0000000	100.7109	189.0128	219.2021	226.6928
61	.0000000	92.00202	168.2245	203.2485	212.8277

```
                                  x             y
Rotor Eccentricity ratio=    9.18515E-02    4.72004E-03
Rotor Misalignment ratio=      .00000         .00000
Force components       =     -65.309         26.652      lbs
Moment components      =      .00000         .00000      in-lb

                         Location
Maximum pressure       (  4, 49)=     250.52      psi
Minimum film thickness (  1,  1)=   9.08149E-04 inches

 Pressurized Pockets:                    Orifice diameter = 1.45228E-02 inches

Pocket              Pressure                 Flow
Number              (psi            )    (in**3/sec     )
    1                222.00              9.76540E-02
    2                189.07                .11555
    3                193.45                .10678
    4                250.52                .10243
                                        ------------
                 Total=                  .42242

Axial flow from left=     -.42242     in**3/sec
Axial flow  to right=   -1.48030E-17  in**3/sec
Overall flow error  =    7.40149E-17  in**3/sec
Torque about z-axis =     1.5079      in-lb
Power loss          =     568.48      in-lb/sec

Running time =  2511.800 sec
```

Pressures & velocities written to file:icyli3.888

Total running time: 2513.940 sec

Listing of sample I4

```
  Incompressible CYLindrical seal program (ICYL)
TIME:10:22:35   DATE:10/26/91 INPUT FILE:ICYLI4
 &INPUTS
 TITLE='4-POCKET SEAL: FULL MODEL AT ECCENTRIC MISALIGNED POSITION'
 CREF=0.001, RADIUS=1., LENGTH=1., RPMJ=3600., PSUP=400, PCAV=-1000,
 XMU=1.E-6, RHO=1.E-4,
 M=9, N=61, ISYM=0,
 alfa=0.1, EX=0.1, ISTIFF=2,
 dorif=  1.452279376501468E-002,
 NPOCK=4, M1=  3,  3,  3,  3,
          M2=  7,  7,  7,  7,
          N1=  3, 18, 33, 48,
          N2= 14, 29, 44, 59,
          PPOCK=4*200,
 /

 &INPUTS ISTOP=1/
```

```
 4-POCKET SEAL: FULL MODEL AT ECCENTRIC MISALIGNED POSITION

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000     inches
 Seal Length =   1.0000     inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000     inches
 Housing Roughness =   .00000     inches
 Rotor Angular Velocity =   3600.0     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                            Left        Right
 Pressure at top    =   .00000      .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =   8
 Number of circumferential grid intervals =  60

 Data for   4 pressurized pockets:
 Orifice diameter =  1.45228E-02 inches
 Supply pressure =   400.00     psi
 Discharge Coeff. =  .60000

Pocket           Axial     Circumferential        Pressure
Number        Start   End      Start   End        (psi          )
  1              3     7          3    14           200.00
  2              3     7         18    29           200.00
  3              3     7         33    44           200.00
  4              3     7         48    59           200.00

 Pressure scale P0=  400.00     psi  .
 Dimensionless parameters:
    Speed of rotor surface              XLj=  5.6549
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI= 1.38889E-04
    Couette Reynolds numbers            Re0=  37.699
    Poisseuille Reynolds numbers        Re0s=  40.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5	6	7	8	9
1	.0000000	89.08993	160.4646	192.2050	199.7563	189.3155	155.2693	83.45992	.0000000
2	.0000000	92.23979	169.4348	195.7334	201.4815	193.5424	165.3375	86.42637	.0000000
3	.0000000	103.3561	212.8134	213.1463	213.1498	213.1444	212.7266	97.77085	.0000000
4	.0000000	107.1503	213.0003	213.1527	213.1527	213.1527	212.9474	101.1056	.0000000
5	.0000000	108.4726	213.0064	213.1527	213.1527	213.1527	212.9415	101.8705	.0000000
6	.0000000	108.9581	213.0088	213.1527	213.1527	213.1527	212.9313	101.8578	.0000000
7	.0000000	109.1440	213.0096	213.1527	213.1527	213.1527	212.9192	101.6403	.0000000
8	.0000000	109.2050	213.0091	213.1527	213.1527	213.1527	212.9062	101.3971	.0000000
9	.0000000	109.1920	213.0075	213.1527	213.1527	213.1527	212.8923	101.1754	.0000000
10	.0000000	109.0974	213.0049	213.1527	213.1527	213.1527	212.8777	100.9616	.0000000
11	.0000000	108.8417	213.0009	213.1527	213.1527	213.1527	212.8620	100.6680	.0000000
12	.0000000	108.1593	212.9947	213.1527	213.1527	213.1527	212.8438	100.0187	.0000000
13	.0000000	106.2316	212.9828	213.1527	213.1527	213.1527	212.8157	98.18077	.0000000
14	.0000000	100.5696	212.6553	213.1210	213.1272	213.1078	212.2193	92.64152	.0000000
15	.0000000	83.85225	155.7849	179.1101	184.0239	176.6685	150.3504	76.16261	.0000000
16	.0000000	74.42609	134.4242	160.7542	166.8693	157.7037	128.2447	67.36892	.0000000
17	.0000000	74.59571	137.4977	158.7133	163.3222	156.5806	132.8516	68.37598	.0000000
18	.0000000	82.23674	169.8600	170.1323	170.1348	170.1294	169.6130	76.97050	.0000000
19	.0000000	84.60710	169.9951	170.1363	170.1363	170.1363	169.8759	79.96930	.0000000
20	.0000000	85.26264	169.9904	170.1363	170.1363	170.1363	169.8770	81.13411	.0000000
21	.0000000	85.36978	169.9831	170.1363	170.1363	170.1363	169.8748	81.72554	.0000000
22	.0000000	85.29990	169.9749	170.1363	170.1363	170.1363	169.8728	82.14714	.0000000
23	.0000000	85.16971	169.9662	170.1363	170.1363	170.1363	169.8717	82.52620	.0000000
24	.0000000	85.01150	169.9570	170.1363	170.1363	170.1363	169.8717	82.89837	.0000000
25	.0000000	84.82075	169.9476	170.1363	170.1363	170.1363	169.8730	83.26092	.0000000
26	.0000000	84.55084	169.9378	170.1363	170.1363	170.1363	169.8752	83.57150	.0000000
27	.0000000	84.04940	169.9268	170.1363	170.1363	170.1363	169.8774	83.69067	.0000000
28	.0000000	82.85009	169.9114	170.1363	170.1363	170.1363	169.8760	83.18680	.0000000
29	.0000000	79.53563	169.6114	170.1252	170.1323	170.1265	169.5992	80.72557	.0000000
30	.0000000	69.98690	132.3389	154.6906	160.7615	155.8371	134.4626	72.35414	.0000000
31	.0000000	67.23669	124.4572	151.3700	159.3160	152.8561	127.1630	70.24107	.0000000
32	.0000000	72.88389	138.7330	161.8017	167.9811	162.9332	140.8956	76.11981	.0000000
33	.0000000	84.82529	183.6474	184.3591	184.3710	184.3620	183.7554	88.20529	.0000000
34	.0000000	88.67321	184.0677	184.3834	184.3834	184.3834	184.1345	92.59281	

	.0000000							
35	.0000000	89.83025	184.0738	184.3834	184.3834	184.3834	184.1544	94.35895
	.0000000							
36	.0000000	90.12799	184.0740	184.3834	184.3834	184.3834	184.1681	95.24979
	.0000000							
37	.0000000	90.15883	184.0738	184.3834	184.3834	184.3834	184.1802	95.83708
	.0000000							
38	.0000000	90.11440	184.0746	184.3834	184.3834	184.3834	184.1915	96.30452
	.0000000							
39	.0000000	90.05440	184.0767	184.3834	184.3834	184.3834	184.2022	96.70568
	.0000000							
40	.0000000	89.98832	184.0802	184.3834	184.3834	184.3834	184.2124	97.04500
	.0000000							
41	.0000000	89.88628	184.0848	184.3834	184.3834	184.3834	184.2217	97.29211
	.0000000							
42	.0000000	89.63393	184.0896	184.3834	184.3834	184.3834	184.2300	97.34724
	.0000000							
43	.0000000	88.86691	184.0915	184.3834	184.3834	184.3834	184.2358	96.90639
	.0000000							
44	.0000000	86.44697	183.8528	184.3810	184.3834	184.3828	184.1323	95.03004
	.0000000							
45	.0000000	78.98135	149.8828	176.3865	184.3287	179.8380	157.1244	88.86683
	.0000000							
46	.0000000	78.91841	146.9995	180.0622	190.7993	184.7256	156.2056	89.43954
	.0000000							
47	.0000000	88.19355	169.3744	198.5677	207.0698	202.1205	176.9323	98.52414
	.0000000							
48	.0000000	104.7516	230.0129	230.9469	230.9653	230.9596	230.4885	114.1005
	.0000000							
49	.0000000	110.4989	230.6127	230.9825	230.9825	230.9825	230.7966	119.0872
	.0000000							
50	.0000000	112.5743	230.6442	230.9825	230.9825	230.9825	230.8074	120.4469
	.0000000							
51	.0000000	113.4539	230.6652	230.9825	230.9825	230.9825	230.8124	120.5511
	.0000000							
52	.0000000	113.9541	230.6833	230.9825	230.9825	230.9825	230.8150	120.1870
	.0000000							
53	.0000000	114.3405	230.7000	230.9825	230.9825	230.9825	230.8160	119.6184
	.0000000							
54	.0000000	114.6914	230.7156	230.9825	230.9825	230.9825	230.8157	118.9327
	.0000000							
55	.0000000	115.0091	230.7300	230.9825	230.9825	230.9825	230.8141	118.1443
	.0000000							
56	.0000000	115.2277	230.7430	230.9825	230.9825	230.9825	230.8110	117.1953
	.0000000							
57	.0000000	115.1250	230.7536	230.9825	230.9825	230.9825	230.8056	115.8548
	.0000000							
58	.0000000	114.0098	230.7587	230.9825	230.9825	230.9825	230.7948	113.3786
	.0000000							
59	.0000000	109.7321	230.4903	230.9677	230.9738	230.9657	230.4997	107.4665
	.0000000							
60	.0000000	95.77971	177.5416	204.7644	210.6587	202.5449	173.4763	91.28538
	.0000000							
61	.0000000	89.08993	160.4646	192.2050	199.7563	189.3155	155.2693	83.45992
	.0000000							

		x	y	
Rotor Eccentricity ratio	=	.10000	.00000	
Rotor Misalignment ratio	=	.10000	.00000	
Force components	=	-64.893	26.410	lbs
Moment components	=	-1.3342	.52800	in-lb

	Location		
Maximum pressure	(4, 49)=	230.98	psi
Minimum film thickness	(1, 8)=	8.58772E-04	inches

Pressurized Pockets: Orifice diameter = 1.45228E-02 inches

Pocket Pressure Flow

Number	(psi)	(in**3/sec)
1	213.15	.19213
2	170.14	.21310
3	184.38	.20639
4	230.98	.18274
	Total=	.79437

```
Axial flow from left=     -.39963      in**3/sec
Axial flow  to right=      .39474      in**3/sec
Overall flow error  =     1.12062E-08  in**3/sec
Torque about z-axis =      1.5127      in-lb
Power loss          =      570.28      in-lb/sec
```

Dynamic Coefficients (Force unit / displacement unit)

Disp.	x inches	y inches	α radians	ß radians	Force unit
Kx	6.43056E+05	2.63577E+05	-4367.6	-856.47	lbs
Ky	-2.64672E+05	6.54020E+05	518.76	2609.9	lbs
Kα	178.62	-320.15	6649.1	2714.2	in-lb
Kß	-191.53	-228.69	-2673.1	6742.1	in-lb
Bx	1408.5	4.0172	1.0532	11.654	lbs-sec
By	3.6449	1403.7	-46.774	-36.539	lbs-sec
Bα	1.0063	1.92364E-02	14.206	4.68492E-02	in-lb-sec
Bß	-4.07539E-03	-.84598	4.60290E-02	14.481	in-lb-sec

```
Critical mass       =    18.389     lb-sec**2/in
Threshold Frequency=     187.80      rad./sec

Running time = 33870.030 sec
```

```
 Pressures & velocities written to file:icyli4.888

Total running time:  33873.760 sec
```

Listing of sample I5

```
  Incompressible CYLindrical seal program (ICYL)
TIME:14:25:58   DATE:11/01/91 INPUT FILE:ICYLI5
 &INPUTS
 TITLE='8-POCK CALCULATION OF ORIFICE DIAMETER'
 CREF=0.001, RADIUS=1., LENGTH=1., RPMJ=3600., PSUP=400, PCAV=-1000,
 XMU=1.E-6, RHO=1.E-4,
 M=11, N=61, XKE=0,
 ECR= 1.e-8, 1.E-6, 0.0001,
 TOL=     0, 1.E-8, 0.0001,
 NIT=    21,    21,      5,
 NPOCK=8, M1=  3,  3,  3,  3,   7,  7,  7,  7,
          M2=  5,  5,  5,  5,   9,  9,  9,  9,
          N1=  3, 18, 33, 48,   3, 18, 33, 48,
          N2= 14, 29, 44, 59,  14, 29, 44, 59,
          PPOCK=8*200,
 /

 &INPUTS ISTOP=1/
```

```
 8-POCK CALCULATION OF ORIFICE DIAMETER

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =   1.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =    3600.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  .00000

                          Left        Right
 Pressure at top    =    .00000      .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =  10
 Number of circumferential grid intervals =  60

 Data for   8 pressurized pockets:
 Supply pressure =    400.00      psi
 Discharge Coeff. =  .60000

Pocket            Axial    Circumferential        Pressure
Number          Start   End      Start   End        (psi           )
  1                3     5           3    14          200.00
  2                3     5          18    29          200.00
  3                3     5          33    44          200.00
  4                3     5          48    59          200.00
  5                7     9           3    14          200.00
  6                7     9          18    29          200.00
  7                7     9          33    44          200.00
  8                7     9          48    59          200.00

 Pressure scale P0=  400.00      psi
 Dimensionless parameters:
    Speed of rotor surface              XLj=  5.6549
    Speed of housing surface            XLb=  .00000
    Inertia pressure drop coefficient XLI=  .00000
    Couette Reynolds numbers            Re0=  37.699
    Poisseuille Reynolds numbers        ReOs=  40.000

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

```
Orifice diameter calculated:
dorif=  1.141938166547165E-002
```

Outputs:

Pressure:	1	2	3	4	5	6	7	8	9	10	11
1	.0000000	70.48159	129.4067	162.3713	177.6811	181.8248	177.6811	162.3713	129.4067	70.48159	.0000000
2	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516	143.6412	76.81811	.0000000
3	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000	200.0000	94.11537	.0000000
4	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000	200.0000	98.50621	.0000000
5	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000	200.0000	99.62078	.0000000
6	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000	200.0000	99.90364	.0000000
7	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000	200.0000	99.97517	.0000000
8	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000	200.0000	99.99222	.0000000
9	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000	200.0000	99.99222	.0000000
10	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000	200.0000	99.97517	.0000000
11	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000	200.0000	99.90364	.0000000
12	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000	200.0000	99.62078	.0000000
13	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000	200.0000	98.50621	.0000000
14	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000	200.0000	94.11537	.0000000
15	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516	143.6412	76.81811	.0000000
16	.0000000	70.48159	129.4067	162.3713	177.6811	181.8248	177.6811	162.3713	129.4067	70.48159	.0000000
17	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516	143.6412	76.81811	.0000000
18	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000	200.0000	94.11537	.0000000
19	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000	200.0000	98.50621	.0000000
20	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000	200.0000	99.62078	.0000000
21	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000	200.0000	99.90364	.0000000
22	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000	200.0000	99.97517	.0000000
23	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000	200.0000	99.99222	.0000000
24	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000	200.0000	99.99222	.0000000
25	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000	200.0000	99.97517	.0000000
26	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000	200.0000	99.90364	.0000000
27	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000	200.0000	99.62078	.0000000
28	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000	200.0000	98.50621	.0000000
29	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000	200.0000	94.11537	.0000000
30	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516	143.6412	76.81811	.0000000
31	.0000000	70.48159	129.4067	162.3713	177.6811	181.8248	177.6811	162.3713			

	129.4067	70.48159	.0000000					
32	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516
	143.6412	76.81811	.0000000					
33	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000
	200.0000	94.11537	.0000000					
34	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000
	200.0000	98.50621	.0000000					
35	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000
	200.0000	99.62078	.0000000					
36	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000
	200.0000	99.90364	.0000000					
37	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000
	200.0000	99.97517	.0000000					
38	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000
	200.0000	99.99222	.0000000					
39	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000
	200.0000	99.99222	.0000000					
40	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000
	200.0000	99.97517	.0000000					
41	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000
	200.0000	99.90364	.0000000					
42	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000
	200.0000	99.62078	.0000000					
43	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000
	200.0000	98.50621	.0000000					
44	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000
	200.0000	94.11537	.0000000					
45	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516
	143.6412	76.81811	.0000000					
46	.0000000	70.48159	129.4067	162.3713	177.6811	181.8248	177.6811	162.3713
	129.4067	70.48159	.0000000					
47	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516
	143.6412	76.81811	.0000000					
48	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000
	200.0000	94.11537	.0000000					
49	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000
	200.0000	98.50621	.0000000					
50	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000
	200.0000	99.62078	.0000000					
51	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000
	200.0000	99.90364	.0000000					
52	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000
	200.0000	99.97517	.0000000					
53	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000
	200.0000	99.99222	.0000000					
54	.0000000	99.99222	200.0000	200.0000	200.0000	199.9954	200.0000	200.0000
	200.0000	99.99222	.0000000					
55	.0000000	99.97517	200.0000	200.0000	200.0000	199.9854	200.0000	200.0000
	200.0000	99.97517	.0000000					
56	.0000000	99.90364	200.0000	200.0000	200.0000	199.9433	200.0000	200.0000
	200.0000	99.90364	.0000000					
57	.0000000	99.62078	200.0000	200.0000	200.0000	199.7770	200.0000	200.0000
	200.0000	99.62078	.0000000					
58	.0000000	98.50621	200.0000	200.0000	200.0000	199.1216	200.0000	200.0000
	200.0000	98.50621	.0000000					
59	.0000000	94.11537	200.0000	200.0000	200.0000	196.5398	200.0000	200.0000
	200.0000	94.11537	.0000000					
60	.0000000	76.81811	143.6412	172.0516	183.8035	186.3690	183.8035	172.0516
	143.6412	76.81811	.0000000					
61	.0000000	70.48159	129.4067	162.3713	177.6811	181.8248	177.6811	162.3713
	129.4067	70.48159	.0000000					

		x	y
Rotor Eccentricity ratio=		.00000	.00000
Rotor Misalignment ratio=		.00000	.00000
Force components	=	-2.42709E-13	1.41060E-12 lbs
Moment components	=	-2.63131E-16	-9.31366E-16 in-lb

Location

```
Maximum pressure       (  3,   3)=     200.00      psi
Minimum film thickness (  1,   1)=    1.00000E-03 inches

 Pressurized Pockets:                    Orifice diameter = 1.14194E-02 inches

Pocket              Pressure                Flow
Number              (psi           )     (in**3/sec      )
    1                200.00               .12290
    2                200.00               .12290
    3                200.00               .12290
    4                200.00               .12290
    5                200.00               .12290
    6                200.00               .12290
    7                200.00               .12290
    8                200.00               .12290
                                       ___________
                 Total=                .98321

Axial flow from left=     -.49161      in**3/sec
Axial flow  to right=      .49161      in**3/sec
Torque about z-axis =      1.6739      in-lb
Power loss          =      631.04      in-lb/sec

Running time =   431.090 sec
________________________________________________________________________________
  Pressures & velocities written to file:ICYLi5.888

 Total running time:    434.130 sec
```

Listing of sample I6

```
 .
 Incompressible CYLindrical seal program (ICYL)
TIME:17:53:07   DATE:11/01/91 INPUT FILE:ICYLI6
 Now iterate to find pocket pressures at eccentric misaligned position:
 &INPUTS
 TITLE='TEST OF ITERATIONS FOR POCKET PRESSURES',
 CREF=0.001, RADIUS=1., LENGTH=1.,
 RPMJ=3600., RPMB=0.,
 XMU=1.E-6, RHO=1.E-4,
 M=11, N=61,
 PL1=    0, PR1= 0, PCAV=-1000, XKE=0, ISYM=0, IPER=1,
 ECR= 1.e-8, 1.E-6, 0.0001,
 TOL=     0, 1.E-8, 0.0001,
 NIT=    21,    21,      5,
          dorif=  1.141938166547165E-002,
 alfa=0.4, EX=0.4,
          PSUP=400,
 NPOCK=8, M1=  3,  3,  3,  3,   7,  7,  7,  7,
          M2=  5,  5,  5,  5,   9,  9,  9,  9,
          N1=  3, 18, 33, 48,   3, 18, 33, 48,
          N2= 14, 29, 44, 59,  14, 29, 44, 59,
          PPOCK=8*200,
 /

 &INPUTS ISTOP=1/
```

```
 TEST OF ITERATIONS FOR POCKET PRESSURES

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =   1.0000      inches
 Clearance =  1.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =    .00000      inches
 Rotor Angular Velocity =   3600.0      r/min.
 Housing Angular Velocity =    .00000      r/min.
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  .00000

.                        Left        Right
 Pressure at top     =    .00000       .00000      psi
 Viscosity =  1.00000E-06 psi-sec
 Density =  1.00000E-04 lb-s**2/in**4

 Number of axial grid intervals =  10
 Number of circumferential grid intervals =  60

 Data for   8 pressurized pockets:
 Orifice diameter =  1.14194E-02 inches
 Supply pressure =   400.00      psi
 Discharge Coeff. =  .60000
```

Pocket Number	Axial Start	Axial End	Circumferential Start	Circumferential End	Pressure (psi)
1	3	5	3	14	200.00
2	3	5	18	29	200.00
3	3	5	33	44	200.00
4	3	5	48	59	200.00
5	7	9	3	14	200.00
6	7	9	18	29	200.00
7	7	9	33	44	200.00
8	7	9	48	59	200.00

```
 Pressure scale P0=  400.00      psi
 Dimensionless parameters:
```

```
Speed of rotor surface             XLj=  5.6549
Speed of housing surface           XLb=  .00000
Inertia pressure drop coefficient  XLI=  .00000
Couette Reynolds numbers           Re0=  37.699
Poisseuille Reynolds numbers       Re0s=  40.000
```

Friction formula based on Moody diagram (Nelson)
Newton-Raphson itertions for velocity components

Outputs:

Pressure:	1	2	3	4	5	6	7	8	9	10	11
1	.0000000	130.4829	217.8290	256.5466	264.3078	252.8946	229.6326	193.7260	139.9666	63.92218	.0000000
2	.0000000	143.4617	239.5841	271.5137	271.2029	240.3574	203.8959	173.3869	132.1773	58.16562	.0000000
3	.0000000	168.5588	308.2763	308.2763	308.2763	240.3891	187.6475	187.6475	187.6475	71.84300	.0000000
4	.0000000	176.6025	308.2763	308.2763	308.2763	238.3894	187.6475	187.6475	187.6475	75.16327	.0000000
5	.0000000	179.1271	308.2763	308.2763	308.2763	236.2741	187.6475	187.6475	187.6475	76.27490	.0000000
6	.0000000	179.2969	308.2763	308.2763	308.2763	234.5516	187.6475	187.6475	187.6475	76.97869	.0000000
7	.0000000	178.1317	308.2763	308.2763	308.2763	233.3344	187.6475	187.6475	187.6475	77.63694	.0000000
8	.0000000	176.1854	308.2763	308.2763	308.2763	232.6052	187.6475	187.6475	187.6475	78.30042	.0000000
9	.0000000	173.9183	308.2763	308.2763	308.2763	232.2907	187.6475	187.6475	187.6475	78.95874	.0000000
10	.0000000	171.6865	308.2763	308.2763	308.2763	232.2707	187.6475	187.6475	187.6475	79.58339	.0000000
11	.0000000	169.5955	308.2763	308.2763	308.2763	232.3123	187.6475	187.6475	187.6475	80.09900	.0000000
12	.0000000	167.1481	308.2763	308.2763	308.2763	231.7779	187.6475	187.6475	187.6475	80.24461	.0000000
13	.0000000	162.0911	308.2763	308.2763	308.2763	228.5224	187.6475	187.6475	187.6475	79.05763	.0000000
14	.0000000	146.2260	308.2763	308.2763	308.2763	214.7993	187.6475	187.6475	187.6475	72.94982	.0000000
15	.0000000	90.18144	167.0328	191.2251	190.4568	162.0950	142.5273	127.4706	102.7988	48.48432	.0000000
16	.0000000	56.88384	106.1717	129.3916	133.4310	123.3255	110.4894	95.17533	71.57287	35.24503	.0000000
17	.0000000	46.68328	90.10921	107.1790	110.8259	104.0376	95.15848	84.98402	67.59722	32.96338	.0000000
18	.0000000	52.23276	112.6833	112.6833	112.6833	99.11886	91.31909	91.31909	91.31909	38.76543	.0000000
19	.0000000	54.02451	112.6833	112.6833	112.6833	98.32302	91.31909	91.31909	91.31909	40.51414	.0000000
20	.0000000	54.85158	112.6833	112.6833	112.6833	98.48348	91.31909	91.31909	91.31909	41.27144	.0000000
21	.0000000	55.35220	112.6833	112.6833	112.6833	98.84660	91.31909	91.31909	91.31909	41.78562	.0000000
22	.0000000	55.67869	112.6833	112.6833	112.6833	99.23449	91.31909	91.31909	91.31909	42.24285	.0000000
23	.0000000	55.87631	112.6833	112.6833	112.6833	99.60726	91.31909	91.31909	91.31909	42.69174	.0000000
24	.0000000	55.96640	112.6833	112.6833	112.6833	99.95823	91.31909	91.31909	91.31909	43.14678	.0000000
25	.0000000	55.95982	112.6833	112.6833	112.6833	100.2890	91.31909	91.31909	91.31909	43.61278	.0000000
26	.0000000	55.84515	112.6833	112.6833	112.6833	100.6042	91.31909	91.31909	91.31909	44.08725	.0000000
27	.0000000	55.53333	112.6833	112.6833	112.6833	100.9137	91.31909	91.31909	91.31909	44.54604	.0000000
28	.0000000	54.64889	112.6833	112.6833	112.6833	101.2465	91.31909	91.31909			

	91.31909	44.87920	.0000000					
29	.0000000	51.74133	112.6833	112.6833	112.6833	101.7069	91.31909	91.31909
	91.31909	44.62936	.0000000					
30	.0000000	41.29063	79.03530	95.88463	103.0309	102.6936	98.60515	91.88796
	76.63144	41.92438	.0000000					
31	.0000000	38.02825	71.76336	91.85782	102.7770	108.1872	108.6160	101.1350
	81.85769	45.56576	.0000000					
32	.0000000	42.33820	81.55751	99.28093	109.2327	119.1436	126.8308	122.4204
	104.3224	57.03545	.0000000					
33	.0000000	52.75203	116.2076	116.2076	116.2076	132.4448	157.8960	157.8960
	157.8960	75.89877	.0000000					
34	.0000000	55.13913	116.2076	116.2076	116.2076	135.8487	157.8960	157.8960
	157.8960	81.77784	.0000000					
35	.0000000	55.55281	116.2076	116.2076	116.2076	136.7324	157.8960	157.8960
	157.8960	84.29023	.0000000					
36	.0000000	55.48657	116.2076	116.2076	116.2076	136.9805	157.8960	157.8960
	157.8960	85.98683	.0000000					
37	.0000000	55.31302	116.2076	116.2076	116.2076	137.0792	157.8960	157.8960
	157.8960	87.55463	.0000000					
38	.0000000	55.12774	116.2076	116.2076	116.2076	137.1577	157.8960	157.8960
	157.8960	89.18650	.0000000					
39	.0000000	54.95742	116.2076	116.2076	116.2076	137.2556	157.8960	157.8960
	157.8960	90.94329	.0000000					
40	.0000000	54.81127	116.2076	116.2076	116.2076	137.3989	157.8960	157.8960
	157.8960	92.85102	.0000000					
41	.0000000	54.69223	116.2076	116.2076	116.2076	137.6467	157.8960	157.8960
	157.8960	94.93387	.0000000					
42	.0000000	54.59303	116.2076	116.2076	116.2076	138.2188	157.8960	157.8960
	157.8960	97.26026	.0000000					
43	.0000000	54.46720	116.2076	116.2076	116.2076	140.0091	157.8960	157.8960
	157.8960	100.1266	.0000000					
44	.0000000	54.10637	116.2076	116.2076	116.2076	146.7303	157.8960	157.8960
	157.8960	104.8674	.0000000					
45	.0000000	52.63266	102.9705	131.1434	151.1386	173.9196	188.5502	190.6541
	174.7586	117.4007	.0000000					
46	.0000000	60.21915	117.7087	156.8529	184.8919	209.8053	228.6363	231.7100
	209.4733	139.9518	.0000000					
47	.0000000	79.45947	160.4956	199.6958	224.9300	253.1794	282.8768	288.2178
	265.4273	173.8130	.0000000					
48	.0000000	110.9175	264.2678	264.2678	264.2678	297.3773	364.2832	364.2832
	364.2832	217.2070	.0000000					
49	.0000000	119.6520	264.2678	264.2678	264.2678	309.7413	364.2832	364.2832
	364.2832	229.7003	.0000000					
50	.0000000	122.4499	264.2678	264.2678	264.2678	313.5413	364.2832	364.2832
	364.2832	232.5090	.0000000					
51	.0000000	123.8194	264.2678	264.2678	264.2678	315.0482	364.2832	364.2832
	364.2832	231.2911	.0000000					
52	.0000000	124.9963	264.2678	264.2678	264.2678	315.9314	364.2832	364.2832
	364.2832	227.5158	.0000000					
53	.0000000	126.3399	264.2678	264.2678	264.2678	316.6042	364.2832	364.2832
	364.2832	221.6764	.0000000					
54	.0000000	127.9720	264.2678	264.2678	264.2678	317.1297	364.2832	364.2832
	364.2832	214.1974	.0000000					
55	.0000000	129.9430	264.2678	264.2678	264.2678	317.4619	364.2832	364.2832
	364.2832	205.6270	.0000000					
56	.0000000	132.2605	264.2678	264.2678	264.2678	317.4883	364.2832	364.2832
	364.2832	196.5200	.0000000					
57	.0000000	134.8425	264.2678	264.2678	264.2678	316.9230	364.2832	364.2832
	364.2832	187.0038	.0000000					
58	.0000000	137.2878	264.2678	264.2678	264.2678	314.7725	364.2832	364.2832
	364.2832	175.5240	.0000000					
59	.0000000	137.9061	264.2678	264.2678	264.2678	307.1324	364.2832	364.2832
	364.2832	154.6584	.0000000					
60	.0000000	129.5640	223.0608	257.8107	269.3226	278.4254	279.9925	255.4045
	204.2068	96.19360	.0000000					
61	.0000000	130.4829	217.8290	256.5466	264.3078	252.8946	229.6326	193.7260
	139.9666	63.92218	.0000000					

x y

```
Rotor Eccentricity ratio=     .40000          .00000
Rotor Misalignment ratio=     .40000          .00000
Force components       =    -249.42          93.319     lbs
Moment components      =    -25.525          5.7379     in-lb

                        Location
Maximum pressure       (  7, 48)=    364.28     psi
Minimum film thickness ( 11, 54)=   4.35090E-04 inches

 Pressurized Pockets:                  Orifice diameter = 1.14194E-02 inches

Pocket              Pressure              Flow
Number              (psi          )     (in**3/sec      )
    1                308.28             8.32304E-02
    2                112.68              .14731
    3                116.21              .14640
    4                264.27              .10125
    5                187.65              .12664
    6                91.319              .15269
    7                157.90              .13522
    8                364.28             5.19371E-02
                                     ___________
              Total=                  .94467

Axial flow from left=    -.50069     in**3/sec
Axial flow  to right=     .44398     in**3/sec
Torque about z-axis =     1.9235     in-lb
Power loss          =     725.15     in-lb/sec

Running time = 15545.750 sec
_______________________________________________________________________________
  Pressures & velocities written to file:ICYLi6.888

 Total running time:  15550.750 sec ( 4.32 hrs )
```

Listing of sample 015

```
  Incompressible CYLindrical seal program (ICYL)
TIME:17:09:54   DATE:19/12/91 INPUT FILE:ICYL015
 &inputs
 TITLE='LOx at 6000 psia and 200R, 30000 RPM vs ROUGHB'
 units='ENGLISH'
 cref=.005, radius=1, length=2, ex=0.1
 rho=2.2e-4, xmu=1.0e-8, rpmj=30000
 istiff=-2, maxdit=2, pcav=-1.e10,
 m=5, n=31
        psup=6000, pr1=6000, ipar=14, npar=-4, par1=1.e-6, par2=1.e-3, /

 &INPUTS istop=1/

 &INPUTS PSUP=5000, PR1=5000, ipar=14, npar= -4, par1=1.e-6, par2=1.e-3, /
 &INPUTS PSUP=4000, PR1=4000, ipar=14, npar= -4, par1=1.e-6, par2=1.e-3, /
 &INPUTS PSUP=3000, PR1=3000, ipar=14, npar=-10, par1=1.e-6, par2=1.e-3, /
```

```
  Parameter variation: parameter          14
  ROUGHB set to:  1.000000000000000E-006
            1 out of           -4 values

 LOx at 6000 psia and 200R, 30000 RPM vs ROUGHB

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000      inches
 Seal Length =   2.0000      inches
 Clearance =  5.00000E-03 inches
 Rotor Roughness =    .00000      inches
 Housing Roughness =  1.00000E-06 inches
 Rotor Angular Velocity =   30000.     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                         Left        Right
 Pressure at top    =   .00000      6000.0      psi
 Viscosity =  1.00000E-08 psi-sec
 Density =  2.20000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  30

 Pressure scale P0=  6000.0      psi
 Dimensionless parameters:
    Speed of rotor surface            XLj= 1.25664E-03
    Speed of housing surface          XLb=  .00000
    Inertia pressure drop coefficient XLI=  28646.
    Couette Reynolds numbers          Re0= 3.45575E+05
    Poisseuille Reynolds numbers      Re0s= 1.65000E+09

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	1143.144	2291.761	3451.933	4634.058
2	.0000000	1134.206	2279.135	3439.522	4626.126
3	.0000000	1125.257	2265.896	3425.156	4613.715
4	.0000000	1116.803	2252.798	3409.657	4597.507
5	.0000000	1109.284	2240.538	3393.867	4578.385
6	.0000000	1103.039	2229.697	3378.580	4557.356
7	.0000000	1098.298	2220.718	3364.489	4535.477
8	.0000000	1095.180	2213.896	3352.160	4513.782
9	.0000000	1093.712	2209.389	3342.020	4493.229
10	.0000000	1093.847	2207.238	3334.369	4474.660
11	.0000000	1095.485	2207.397	3329.385	4458.779
12	.0000000	1098.489	2209.749	3327.150	4446.139
13	.0000000	1102.699	2214.129	3327.658	4437.148
14	.0000000	1107.939	2220.336	3330.832	4432.068
15	.0000000	1114.024	2228.137	3336.531	4431.024
16	.0000000	1120.759	2237.274	3344.554	4434.014
17	.0000000	1127.937	2247.461	3354.642	4440.912
18	.0000000	1135.336	2258.380	3366.477	4451.476
19	.0000000	1142.719	2269.683	3379.678	4465.344
20	.0000000	1149.831	2280.981	3393.802	4482.042
21	.0000000	1156.397	2291.852	3408.337	4500.982
22	.0000000	1162.129	2301.843	3422.715	4521.466
23	.0000000	1166.735	2310.483	3436.318	4542.698
24	.0000000	1169.934	2317.302	3448.497	4563.797
25	.0000000	1171.478	2321.863	3458.607	4583.829
26	.0000000	1171.181	2323.805	3466.048	4601.838
27	.0000000	1168.947	2322.879	3470.319	4616.905
28	.0000000	1164.800	2319.000	3471.069	4628.207
29	.0000000	1158.899	2312.278	3468.154	4635.081
30	.0000000	1151.541	2303.028	3461.663	4637.087
31	.0000000	1143.144	2291.761	3451.933	4634.058

		x	y	
Rotor Eccentricity ratio	=	.10000	.00000	
Rotor Misalignment ratio	=	.00000	.00000	
Force components	=	-222.99	234.61	lbs
Moment components	=	-28.126	-111.80	in-lb

	Location		
Maximum pressure	(5, 30)=	4637.1	psi
Minimum film thickness	(1, 1)=	4.50000E-03	inches

Axial flow from left=	-114.96	in**3/sec
Axial flow to right=	-114.96	in**3/sec
Overall flow error =	-2.90566E-12	in**3/sec
Torque about z-axis =	10.171	in-lb
Power loss =	31953.	in-lb/sec

```
Dynamic Coefficients ( Force unit / displacement unit )
Disp.            x            y            α            β
                 inches       inches       radians      radians      Force unit

Kx         4.45244E+05  4.69214E+05                                  lbs
Ky        -4.72268E+05  4.45978E+05                                  lbs

Bx          383.29       .19955                                      lbs-sec
By          -.27346      381.09                                      lbs-sec

Critical mass      =     .29392      lb-sec**2/in
Threshold Frequency=     1231.7       rad./sec

Running time =  1595.530 sec
```

```
  Pressures & velocities written to file:icylo15.888

  Parameter variation: parameter          14
  ROUGHB set to:  9.999999999999999E-006
            2 out of           -4 values

 LOx at 6000 psia and 200R, 30000 RPM vs ROUGHB

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000     inches
 Seal Length =   2.0000     inches
 Clearance =  5.00000E-03 inches
 Rotor Roughness =    .00000     inches
 Housing Roughness =  1.00000E-05 inches
 Rotor Angular Velocity =   30000.     r/min.
 Housing Angular Velocity =   .00000     r/min.
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                         Left        Right
 Pressure at top    =   .00000      6000.0      psi
 Viscosity =  1.00000E-08 psi-sec
 Density =  2.20000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  30

 Pressure scale P0=  6000.0      psi
 Dimensionless parameters:
    Speed of rotor surface            XLj= 1.25664E-03
    Speed of housing surface          XLb=  .00000
    Inertia pressure drop coefficient XLI=  28646.
    Couette Reynolds numbers          Re0= 3.45575E+05
    Poisseuille Reynolds numbers      Re0s= 1.65000E+09

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	1216.359	2438.449	3671.268	4923.803
2	.0000000	1208.044	2426.771	3660.026	4917.327
3	.0000000	1199.742	2414.537	3646.963	4906.701
4	.0000000	1191.924	2402.443	3632.827	4892.498
5	.0000000	1184.996	2391.131	3618.383	4875.478
6	.0000000	1179.268	2381.138	3604.353	4856.527
7	.0000000	1174.946	2372.869	3591.373	4836.589
8	.0000000	1172.139	2366.594	3579.962	4816.607
9	.0000000	1170.864	2362.456	3570.520	4797.471
10	.0000000	1171.075	2360.492	3563.328	4779.977
11	.0000000	1172.674	2360.657	3558.561	4764.807
12	.0000000	1175.533	2362.845	3556.304	4752.512
13	.0000000	1179.500	2366.902	3556.563	4743.508
14	.0000000	1184.413	2372.643	3559.280	4738.078
15	.0000000	1190.097	2379.855	3564.333	4736.374
16	.0000000	1196.373	2388.300	3571.546	4738.427
17	.0000000	1203.046	2397.714	3580.687	4744.144
18	.0000000	1209.912	2407.804	3591.467	4753.319
19	.0000000	1216.751	2418.247	3603.539	4765.632
20	.0000000	1223.324	2428.685	3616.493	4780.651
21	.0000000	1229.378	2438.726	3629.860	4797.838
22	.0000000	1234.645	2447.951	3643.115	4816.551
23	.0000000	1238.856	2455.925	3655.686	4836.056
24	.0000000	1241.750	2462.211	3666.976	4855.546
25	.0000000	1243.100	2466.409	3676.388	4874.162
26	.0000000	1242.736	2468.180	3683.367	4891.031
27	.0000000	1240.574	2467.299	3687.450	4905.309
28	.0000000	1236.639	2463.688	3688.312	4916.240
29	.0000000	1231.086	2457.450	3685.813	4923.207
30	.0000000	1224.195	2448.879	3680.031	4925.789
31	.0000000	1216.359	2438.449	3671.268	4923.803

	x	y	
Rotor Eccentricity ratio=	.10000	.00000	
Rotor Misalignment ratio=	.00000	.00000	
Force components =	-205.97	212.83	lbs
Moment components =	-22.146	-104.00	in-lb

	Location		
Maximum pressure	(5, 30)=	4925.8	psi
Minimum film thickness	(1, 1)=	4.50000E-03	inches

Axial flow from left=	-102.67	in**3/sec
Axial flow to right=	-102.67	in**3/sec
Overall flow error =	2.22695E-11	in**3/sec
Torque about z-axis =	11.330	in-lb
Power loss =	35596.	in-lb/sec

```
Dynamic Coefficients ( Force unit / displacement unit )
Disp.             x              y             α             ß
                  inches         inches        radians       radians       Force unit

Kx          4.11105E+05   4.25669E+05                                     lbs
Ky         -4.28547E+05   4.11929E+05                                     lbs

Bx            440.60        .59226                                        lbs-sec
By            -.63188       438.06                                        lbs-sec

Critical mass      =      .43604     lb-sec**2/in
Threshold Frequency=      972.18      rad./sec

Running time =  1480.410 sec
```

```
  Pressures & velocities written to file:icylo15.888

  Parameter variation: parameter          14
  ROUGHB set to:  1.000000000000000E-004
            3 out of           -4 values

 LOx at 6000 psia and 200R, 30000 RPM vs ROUGHB

 Input values:

 Seal Type: Cylindrical seal
 Rotor Radius =    1.0000     inches
 Seal Length =   2.0000     inches
 Clearance =  5.00000E-03 inches
 Rotor Roughness =    .00000     inches
 Housing Roughness =  1.00000E-04 inches
 Rotor Angular Velocity =   30000.     r/min.
 Housing Angular Velocity =    .00000     r/min.
 Periodic conditions at circumferntial ends
 Inertia pressure drop coefficient =  1.0000

                            Left        Right
 Pressure at top    =   .00000      6000.0     psi
 Viscosity =  1.00000E-08 psi-sec
 Density =  2.20000E-04 lb-s**2/in**4

 Number of axial grid intervals =   4
 Number of circumferential grid intervals =  30

 Pressure scale P0=  6000.0      psi
 Dimensionless parameters:
    Speed of rotor surface           XLj= 1.25664E-03
    Speed of housing surface         XLb=  .00000
    Inertia pressure drop coefficient XLI=  28646.
    Couette Reynolds numbers         Re0= 3.45575E+05
    Poisseuille Reynolds numbers     Re0s= 1.65000E+09

 Friction formula based on Moody diagram (Nelson)
  Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	1308.207	2621.804	3944.222	5282.103
2	.0000000	1300.945	2611.716	3934.828	5277.592
3	.0000000	1293.744	2601.213	3923.961	5269.700
4	.0000000	1287.012	2590.895	3912.237	5258.835
5	.0000000	1281.095	2581.305	3900.286	5245.556
6	.0000000	1276.256	2572.894	3888.698	5230.533
7	.0000000	1272.665	2565.999	3877.989	5214.499
8	.0000000	1270.404	2560.836	3868.581	5198.205
9	.0000000	1269.480	2557.515	3860.800	5182.380
10	.0000000	1269.842	2556.057	3854.876	5167.696
11	.0000000	1271.400	2556.414	3850.955	5154.747
12	.0000000	1274.035	2558.487	3849.110	5144.029
13	.0000000	1277.612	2562.141	3849.351	5135.934
14	.0000000	1281.986	2567.211	3851.635	5130.740
15	.0000000	1287.005	2573.514	3855.865	5128.618
16	.0000000	1292.510	2580.842	3861.898	5129.626
17	.0000000	1298.332	2588.969	3869.541	5133.716
18	.0000000	1304.293	2597.641	3878.554	5140.733
19	.0000000	1310.201	2606.579	3888.641	5150.421
20	.0000000	1315.849	2615.477	3899.457	5162.425
21	.0000000	1321.019	2623.998	3910.605	5176.295
22	.0000000	1325.478	2631.782	3921.639	5191.499
23	.0000000	1328.995	2638.458	3932.078	5207.426
24	.0000000	1331.349	2643.655	3941.421	5223.412
25	.0000000	1332.346	2647.035	3949.171	5238.755
26	.0000000	1331.845	2648.316	3954.871	5252.749
27	.0000000	1329.782	2647.316	3958.141	5264.718
28	.0000000	1326.188	2643.982	3958.722	5274.056
29	.0000000	1321.209	2638.414	3956.514	5280.266
30	.0000000	1315.099	2630.882	3951.593	5283.004
31	.0000000	1308.207	2621.804	3944.222	5282.103

```
                                 x              y
Rotor Eccentricity ratio=     .10000         .00000
Rotor Misalignment ratio=     .00000         .00000
Force components        =    -168.87         179.53     lbs
Moment components       =    -14.597        -85.971     in-lb

                        Location
Maximum pressure       ( 5, 30)=     5283.0      psi
Minimum film thickness (  1,  1)=    4.50000E-03 inches

Axial flow from left=     -84.645     in**3/sec
Axial flow  to right=     -84.645     in**3/sec
Overall flow error  =     1.76291E-11 in**3/sec
Torque about z-axis =      12.370     in-lb
Power loss          =      38862.     in-lb/sec
```

```
Dynamic Coefficients ( Force unit / displacement unit )
Disp.            x             y             α             ß
               inches        inches        radians       radians       Force unit

Kx        3.36891E+05   3.59061E+05                                   lbs
Ky       -3.61685E+05   3.37748E+05                                   lbs

Bx          535.84        1.1402                                      lbs-sec
By          -1.1497       532.69                                      lbs-sec

Critical mass      =     .74310     lb-sec**2/in
Threshold Frequency=     674.52      rad./sec

Running time =  1481.070 sec
```

```
 Pressures & velocities written to file:icylo15.888

 Parameter variation: parameter          14
 ROUGHB set to:  1.000000000000000E-003
          4 out of          -4 values

LOx at 6000 psia and 200R, 30000 RPM vs ROUGHB

Input values:

Seal Type: Cylindrical seal
Rotor Radius =    1.0000      inches
Seal Length =   2.0000      inches
Clearance =  5.00000E-03 inches
Rotor Roughness =    .00000      inches
Housing Roughness =  1.00000E-03 inches
Rotor Angular Velocity =    30000.     r/min.
Housing Angular Velocity =    .00000     r/min.
Periodic conditions at circumferntial ends
Inertia pressure drop coefficient =  1.0000

                          Left        Right
Pressure at top    =    .00000      6000.0      psi
Viscosity =  1.00000E-08 psi-sec
Density =  2.20000E-04 lb-s**2/in**4

Number of axial grid intervals =   4
Number of circumferential grid intervals =  30

Pressure scale P0=  6000.0      psi
Dimensionless parameters:
   Speed of rotor surface             XLj= 1.25664E-03
   Speed of housing surface           XLb=  .00000
   Inertia pressure drop coefficient  XLI=  28646.
   Couette Reynolds numbers           Re0= 3.45575E+05
   Poisseuille Reynolds numbers       Re0s= 1.65000E+09

Friction formula based on Moody diagram (Nelson)
 Newton-Raphson itertions for velocity components
```

Outputs:

Pressure:	1	2	3	4	5
1	.0000000	1386.572	2777.651	4174.896	5582.167
2	.0000000	1380.529	2769.380	4167.514	5579.496
3	.0000000	1374.617	2760.914	4159.168	5574.514
4	.0000000	1369.171	2752.733	4150.331	5567.463
5	.0000000	1364.467	2745.266	4141.471	5558.686
6	.0000000	1360.712	2738.858	4133.015	5548.605
7	.0000000	1358.029	2733.754	4125.327	5537.693
8	.0000000	1356.469	2730.100	4118.697	5526.451
9	.0000000	1356.021	2727.958	4113.339	5515.380
10	.0000000	1356.628	2727.318	4109.400	5504.959
11	.0000000	1358.201	2728.117	4106.968	5495.624
12	.0000000	1360.633	2730.257	4106.079	5487.754
13	.0000000	1363.804	2733.612	4106.726	5481.658
14	.0000000	1367.588	2738.041	4108.865	5477.569
15	.0000000	1371.856	2743.385	4112.416	5475.640
16	.0000000	1376.475	2749.471	4117.263	5475.937
17	.0000000	1381.303	2756.114	4123.255	5478.444
18	.0000000	1386.195	2763.107	4130.202	5483.061
19	.0000000	1390.994	2770.226	4137.878	5489.610
20	.0000000	1395.530	2777.224	4146.014	5497.833
21	.0000000	1399.625	2783.834	4154.305	5507.406
22	.0000000	1403.093	2789.771	4162.412	5517.942
23	.0000000	1405.748	2794.744	4169.971	5529.006
24	.0000000	1407.414	2798.465	4176.608	5540.128
25	.0000000	1407.940	2800.677	4181.958	5550.819
26	.0000000	1407.221	2801.173	4185.695	5560.597
27	.0000000	1405.218	2799.828	4187.556	5569.006
28	.0000000	1401.973	2796.627	4187.378	5575.645
29	.0000000	1397.620	2791.681	4185.121	5580.185
30	.0000000	1392.385	2785.234	4180.882	5582.398
31	.0000000	1386.572	2777.651	4174.896	5582.167

```
                                 x             y
Rotor Eccentricity ratio=     .10000        .00000
Rotor Misalignment ratio=     .00000        .00000
Force components       =    -116.96        144.14      lbs
Moment components      =    -8.1298       -60.349      in-lb

                        Location
Maximum pressure       ( 5, 30)=     5582.4     psi
Minimum film thickness ( 1,  1)=   4.50000E-03 inches

Axial flow from left=     -65.181     in**3/sec
Axial flow  to right=     -65.181     in**3/sec
Overall flow error  =   4.09828E-12  in**3/sec
Torque about z-axis =     12.986      in-lb
Power loss          =     40796.      in-lb/sec
```

Dynamic Coefficients (Force unit / displacement unit)

Disp.	x inches	y inches	α radians	β radians	Force unit
Kx	2.33233E+05	2.88276E+05			lbs
Ky	-2.90689E+05	2.33922E+05			lbs
Bx	678.28	1.6477			lbs-sec
By	-1.6487	674.11			lbs-sec

Critical mass = 1.2783 lb-sec**2/in
Threshold Frequency= 428.10 rad./sec

Running time = 1705.440 sec

Pressures & velocities written to file:icylo15.888

Total running time: 6267.000 sec

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12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The computer code ICYL was developed to evaluate the performance of cylindrical seals operating with incompressible fluids. The pressure and velocity distributions within the seal clearance are first evaluated from the governing equations. From these, design quantities such as seal leakage flows, power loss, and resulting forces and moments are calculated. Minimum film thicknesses and maximum pressures as well as critical rotor-dynamics coefficients such as stiffness, damping, and critical mass are evaluated. This users' manual documents the theoretical description, numerical methods, program usage, input and output descriptions, sample problems, code verification, and operating environment of ICYL.

14. SUBJECT TERMS
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